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# EPA-Interagency Coal Cleaning Program: FY 1978 Progress Report

PEDCo Environmental, Inc, Dallas, TX

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

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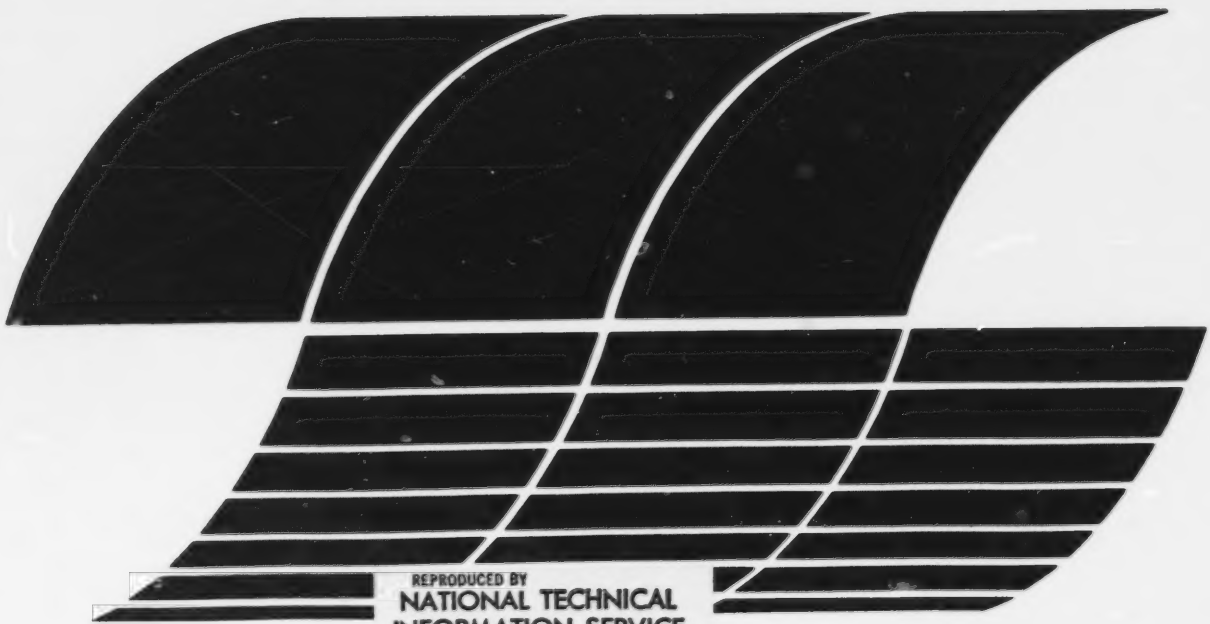
# EPA-Interagency Coal Cleaning Program: FY 1978 Progress Report

## Interagency Energy/Environment R&D Program Report



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16. ABSTRACT The report reviews the progress of EPA's interagency coal cleaning program for 1977. Research into the methodology and economics of physical coal cleaning has continued. The first phase of a physical coal cleaning plant has undegone acceptance tests. In conjunction with that project, investigations are being carried out to optimize the performance of dense media cyclones. A two-stage coal/pyrite floatation demonstration circuit has been installed in a coal preparation plant. In an associated project, adsorption/desorption reactions in the desulfurization of coal by flotation are being studied. High-gradient magnetic separation is being studied for application to coal cleaning. The first phase has been completed in developing a computer program to simulate coal preparation plant operations. A study to identify the costs associated with various physical coal cleaning processes was recently completed. Amajor review of the process technologies and economics of the most advanced chemical coal cleaning processes has been completed. A 1/3-ton/hr Reactor Test Unit has been operated for 4 months to evaluate key process steps of the Meyers process. Improvements have been made to Battelle's hydrothermal process. A extensive review of the environmental impact of coal cleaning has been started. Programs are under way to characterize possible hazardous pollutants in wastes.

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| Coal | Desulfurization | Stationary Sources | 08G,21D |
| Coal Preparation | Magnetic Separators | Coal Cleaning | 08I |
| Assessments | Mathematical Models | Environmental Assessment | 14B 12A |
| Pyrite | Toxicity | Hydrothermal Process | 07A,13H,11F 06T 13I |
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# EPA-Interagency Coal Cleaning Program: FY 1978 Progress Report

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## ABBREVIATIONS

| | |
|---|---|
| AEP | American Electric Power Service Corporation |
| BACT | Best available control technology |
| BAT/BATEA | Best available control technology economically available |
| BPT | Best practical control technology currently available |
| CCC | Chemical coal cleaning |
| CPPDF | Coal preparation process development facility |
| DOE | U. S. Department of Energy |
| EPA | U. S. Environmental Protection Agency |
| EPC | Estimated permissible concentration |
| EPRI | Electric Power Research Institute |
| FGD | Flue gas desulfurization |
| FWPCA | Federal Water Pollution Control Act |
| HGMS | High-gradient magnetic separation |
| IERL-RTP | EPA Industrial Environmental Research Laboratory, Research Triangle Park |
| IGT | Institute of Gas Technology |
| JPL | Jet Propulsion Laboratory, California Institute of Technology |
| LASL | Los Alamos Scientific Laboratory |
| MEG | Multimedia environmental goal |
| NEP | National Energy Plan |
| NSPS | New source performance standards |
| PCC | Physical coal cleaning |
| Penelec | Pennsylvania Electric Company |
| PZC | Point of zero charge |
| RCRA | Resource Conservation and Recovery Act, 1976 |
| ROM | Run-of-mine |
| RTU | Reactor test unit |
| SIP | State Implementation Plan |
| TSS | Total suspended solids |
| TVA | Tennessee Valley Authority |
| USBM | U. S. Bureau of Mines |
| UMW | United Mine Workers of America |

## UNITS

The Systeme International d'Units (S.I.) is used as far as practicable in this report.

The basic units with their equivalents are:

| | | |
|---|---|---|
| meter (m) | = | 3.281 feet |
| kilogram (kg) | = | 2.205 pounds |
| newton (N) | = | 4.5 poundals (approximately) |
| joule (J) | = | $9.47 \times 10^{-4}$ Btu |

Fractions and multiples:

| | | | | | |
|---|---|---|---|---|---|
| $10^{-3}$ | milli | m | $10^{3}$ | kilo | k |
| $10^{-6}$ | micro | μ | $10^{6}$ | mega | M |
| $10^{-9}$ | nano | n | $10^{9}$ | giga | G |
| $10^{-12}$ | pico | p | $10^{12}$ | tera | T |

In addition the following conversions are used:

| | | |
|---|---|---|
| metric ton* (tonne) | = | 1000 kg = 1 Mg |
| short ton* | = | 2000 pounds = 0.907 metric ton |
| long ton* | = | 2240 pounds |

* In this report ton' always denotes a short ton'.

## ACKNOWLEDGMENTS

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The author also wishes to acknowledge James D. Kilgroe (EPA Project Officer) and Richard Hucko, authors of the paper entitled "Interagency Coal Cleaning Technology Developments", upon which a major portion of this report is based.

## EXECUTIVE SUMMARY

The progress of the interagency coal cleaning program for 1977 has been reviewed. The year has been one of transition. Potential applications of coal cleaning, and hence research and development goals, have been greatly affected by new environmental legislation and impending energy legislation. The Clean Air Act Amendments of August 1977 have significantly modified previous clean air legislation, especially as related to its potential impacts on the use of coal cleaning technology. Regulations proposed by EPA effectively preclude the use of coal cleaning as a sole method for complying with $SO_2$ standards in new electric utility boilers. New water regulations limit the concentration of pollutants in effluents from mining and coal preparation facilities.

Research into the methodology and economics of physical coal cleaning has continued. The first phase of a physical coal cleaning plant at Penelec's Homer City Generating Station has been commissioned and has undergone acceptance tests. Further operation awaits the completion of the second phase of the plant, which is expected soon. The plant will be capable of producing medium- and low-sulfur coals to meet Federal and Pennsylvania emission standards of 0.52 μg $SO_2$/J (1.2 lb $SO_2/10^6$ Btu) and 1.7 μg $SO_2$/J (4.0 lb $SO_2/10^6$ Btu) respectively. In conjunction with the Homer City project, investigations are being carried out in order to optimize the performance of dense-medium cyclones. The U. S. Department of Energy (DOE) is conducting these tests at Bruceton, Pennsylvania. Coal cleaning by flotation is also being studied. A two-stage coal/pyrite flotation demonstration circuit has been installed in the Lancashire No. 25 preparation plant. In an associated project, the University of Utah is studying

adsorption/desorption reactions in the desulfurization of coal by flotation. The technique of high-gradient magnetic separation, which has been utilized commercially in the purification of kaolin clay, is being studied by the General Electric Company for application in coal cleaning. A DOE physical coal cleaning test facility has been designed and is soon to be constructed. The facility is needed so that technology or equipment developed by DOE can be demonstrated to industrial representatives in a fully integrated coal preparation plant. Unbiased engineering data thus can be provided on a scope not previously possible. The University of Pittsburgh has completed the first phase in the development of a computer program that will simulate coal preparation plant operations. The program will predict outputs of clean coal and refuse for given plant designs and raw coal feed. Hoffman-Muntner Corporation has recently completed a study to identify the costs associated with various physical coal cleaning processes. Eight preparation plants are discussed.

The development of chemical coal cleaning technology has been studied. A major review of the process technologies and the economics of the most advanced chemical coal cleaning processes have been discussed in detail. For the Meyers Process, a 0.3 Mg/h (1/3 ton/h) Reactor Test Unit (RTU) has been commissioned and operated for a period of 4 months to evaluate various key process steps. However, the RTU has been closed down due to corrosion problems in the main reactor vessel. Continued testing will be dependent upon an evaluation of potential process market applications as affected by the Clean Air Act Ammendments of 1977. Microwave desulfurization of coal, developed by General Electric, is discussed. The Battelle hydrothermal process is also reviewed. This process is still only at a laboratory scale stage of development but significant progress has been made in improving unit operations dealing with leachant-coal separation, leachant regeneration, and dewatering resulting in reduced moisture content of the coal product. The Institute of Gas Technology's hydrodesulfurization process is reported. This process could prove to be

extremely important in the treatment of coal with a high organic sulfur content.

An extensive review of the environmental impact of coal cleaning has been started. Programs to characterize the possible hazardous pollutants and to establish their maximum permissible concentrations in coal preparation plant waste streams have been initiated. The effects of coal preparation pollutants upon humans, aquatic biota, terrestrial biota, and the total ecosystem are being studied. Programs designed to control these pollutants have been inititated and are reported in detail.

# SECTION 1

# INTRODUCTION

Expanded coal production and use is a major goal of our National Energy Plan. A corollary goal is the containment of adverse environmental effects from coal use.

Coal beneficiation or cleaning is an important step in the coal energy cycle. Coal cleaning is used to remove extraneous mineral matter and mining residue. It can also be used as a cost-effective means of removing sulfur from metallurgical coke and from boiler fuels burned to comply with $SO_2$ emission regulations.

Coal cleaning processes generate waste products that must be controlled and disposed of in an environmentally sound manner. In 1976, more than 330 Tg (370 million ton) of coal were physically cleaned, generating more than 97 Tg (107 million ton) of coal cleaning residues. Leachates from improper waste disposal, particulate emissions from thermal drying, and fugitive dust from coal handling pose health and ecological threats.

The U. S. Environmental Protection Agency (EPA) is conducting an interagency energy/environmental program, divided into three basic elements. The principal objectives of these subprograms are to (a) assess and develop coal cleaning technology for removing pollutant-forming contaminants from coal, (b) evaluate the environmental impacts of coal cleaning processes, and (c) develop improved methods of controlling pollution from coal preparation.

This annual report summarizes the progress of the interagency coal cleaning research and development program in 1977 and regulatory activities related to coal cleaning. It includes an analysis of future coal cleaning research and development priorities.

# SECTION 2

# REGULATORY AND TECHNICAL STATUS

Research and development activities under the interagency coal cleaning program are responsive to changing regulatory requirements and energy goals. A review of current regulatory activities and the status of coal cleaning technology provides the context for discussion of progress on recent coal cleaning research and development.

## 2.1 REGULATORY STATUS

### 2.1.1 Air Quality Regulations

In accordance with provisions of the Clean Air Act Amendments of 1970, EPA has set primary and secondary ambient air quality standards, which regulate pollutant levels in order to protect human health and public welfare (property, plant life, and animal life). Ambient air pollutants specified in current EPA regulations relating to coal use include sulfur oxides, nitrogen oxides, and total suspended particulates.

Section 111 of the 1970 Clean Air Act Amendments requires that EPA promulgate emission standards for new stationary sources (sources constructed after the date the regulations are proposed). These new source performance standards (NSPS) specify emission limits only; they do not prescribe types of control systems. Therefore, the owner/operator may select any type of control system, but the standards must be achieved without the privilege of variances or exemptions. The Clean Air Act Amendments of August 1977 significantly modified previous clean air legislation, especially as related to potential impacts on the use of coal cleaning technology. These Amendments specify that all new

stationary sources regulated by EPA must: (a) use best available control technology (BACT); (b) use a method of continuous pollution control; (c) achieve a percentage reduction of the regulated pollutants from fossil-fuel-fired boilers. In the case of fossil-fuel-fired steam generators, any reduction of a pollutant by post-extraction fuel processing may be credited to the percentage reduction requirement.

EPA will soon propose revised NSPS for fossil-fuel-fired boilers used to generate electrical energy. The regulations under consideration require an 85 percent reduction in sulfur between extraction and stack gas emissions, and specify that the sulfur emissions cannot exceed 520 ng $SO_2$/J (1.2 lb $SO_2/10^6$ Btu) of boiler heat input. Emissions below a minimum level (86 to 214 ng $SO_2$/J [0.2 to 0.5 lb $SO_2/10^6$ Btu]) would be exempted from the percentage reduction requirement. Promulgation of these regulations would effectively preclude the use of coal cleaning as a sole method for complying with $SO_2$ standards in new electrical utility boilers.

Other important provisions of the 1977 Clean Air Act Amendments that relate to coal cleaning include the prevention of significant deterioration of air quality in clean air regions, the siting of sources in nonattainment areas, the periodic review of State Implementation Plans (SIP) for complying with National Ambient Air Quality Standards, and the setting of emission standards for potentially hazardous pollutants. The stringency of regulations for nondeterioration and clean air regions may necessitate the use of coal cleaning in combination with flue gas desulfurization (FGD) to comply with $SO_2$ emission standards. Tightening and strict enforcement of emission standards under SIP may expand the market for physically or chemically cleaned coals.

Potentially hazardous pollutants that EPA must consider regulating include arsenic, beryllium, mercury, lead, and polycyclic organic matter, all of which are emitted from coal-fired boilers. If EPA decides that these pollutants from coal combustion

must be regulated, then removal of some of these contaminants by coal cleaning may be an effective control method.

### 2.1.2 Water Pollution Control Regulations

Federal control of water pollution sources associated with coal production, preparation, and consumption is achieved through the issuance of discharge permits that specify limits on discharged effluents. Effluent guidelines are presently based on the best practicable control technology currently available (BPT) and must be based on the best available technology economically available (BATEA or BAT) by 1983, except where modified requirements are in order, pursuant to Section 301 (c) of the Federal Water Pollution Control Act (FWPCA). Effluent regulations are also being issued for new sources. These new source performance standards, mandated by FWPCA Section 306, are intended to be the most stringent standards applied.

State control of water pollution sources associated with coal preparation is achieved through the issuance of permits independently or under the National Pollutant Discharge Elimination System. The permits, which contain limits on the effluents discharged, are issued to each discharger. The objective of such control systems is to achieve or maintain specified ambient water quality standards, which are primarily a state responsibility. The Federal laws are intended to aid in achievement of state standards; however, EPA retains the authority to veto state plans.

On May 13, 1976, EPA promulgated interim final effluent guidelines for four subcategories of existing sources: coal preparation plants; coal storage, refuse storage, and coal preparation plant ancillary areas; acid or ferruginous mine drainage; and alkaline mine drainage. More than ten lawsuits were consolidated and are now pending before the U.S. Court of Appeals for the Fourth Circuit.

On April 26, 1977, EPA promulgated final regulations that incorporated several revisions to the interim final effluent

guidelines published in 1976. Subpart B of these regulations addresses discharges from coal preparation plants and associated areas, including discharges that are pumped, siphoned, or drained from coal storage, refuse storage, and coal preparation plant ancillary areas. Included under these regulations are discharges related to the cleaning or beneficiation of coal of any rank, including bituminous, lignitic, and anthracitic.

The regulations establish the concentrations of pollutants that may be discharged after application of BPT treatment. These limitations differ for discharges that are normally acidic prior to treatment as opposed to those that are normally alkaline. For acidic conditions, the regulations specify limits on pH and the discharge of total iron, manganese, and total suspended solids (TSS). For alkaline conditions, the regulations limit pH and the discharge of total iron and TSS.

On September 19, 1977, EPA published proposed NSPS for the coal mining point source category. These standards establish the concentrations of the pollutants that may be discharged after application of the best available demonstrated control technology. These limitations apply to discharges from facilities that recycle process wastewater and differ according to whether discharges are normally acidic or alkaline prior to treatment. Pollutants regulated include total iron, manganese (acidic conditions only), TSS, and pH. The regulations stipulate that discharges shall not be made from facilities that do not recycle process wastewater.

In 1975, EPA was taken to court by several environmental groups who claimed that EPA had not done a complete job in assessing the pollution of surface waters by industry. On June 7, 1976, the courts decided in favor of the environmentalists, and the machinery for the review of effluent guidelines was set in motion.

First of all, EPA must review its BAT guidelines in the light of the priority pollutants. Designation of these priority pollutants arose from the court case. They consist of approximately 65 compounds or classes of compounds that EPA had failed

to regulate or to take into consideration in the earlier guidelines. The process of naming specific compounds within the classes resulted in a list of 129 priority pollutants.

The courts set deadlines for EPA, aimed at implementing BAT by 1983. The first step is a proposed rule-making by September 30, 1978. By December 31, 1978, after time for comment, EPA is to publish its proposed revised guidelines. Six months later (June 30, 1979), the revised guidelines are to be promulgated. This will give industry four years to implement BAT. However, a 4-month strike by the United Mine Workers of America (UMW) interfered with this schedule. Consequently EPA and the National Coal Association are preparing to request a 6-month delay in the deadlines.

The BAT Review is a three-phase study, the first two phases dealing with technology and the third with economics. The technology phases, centering on the priority pollutants, became known as the screening and verification phases. The object of the screening phase is to determine the presence or absence of the priority pollutants; the object of the verification phase is to confirm the presence of the pollutants and to determine the concentrations. During these two phases, plants are being visited to obtain both technical and economic data. Factors that would affect the economics of a treatment technology are being determined at each site visited. These factors include plant capacity, age, and location; type of process; source of raw materials; end use of product; capital cost; capital recovery; and operating costs. This information is then used to determine the impact and cost-effectiveness of a treatment technology.

The screening phase for the coal mining industry has been completed. Plans are being made to begin the verification phase, which has been delayed by the UMW strike.

In the screening phase, 18 coal preparation plants were visited. Of these, only two were not sampled, one because the plant was closed by a strike and the other because there was no point of discharge.

In addition to the screening tests for the 129 priority pollutants, analyses were made for classic water pollutant parameters and for some elements not on the priority pollutant list. Of the 129 priority pollutants, 24 were found in water from preparation plants and associated areas. Additionally, 12 elements of concern were found that were not on the priority pollutants list. Some of the identified pollutants may be artifacts of the analytical procedures; hence, additional tests will be required to evaluate their authenticity.

### 2.1.3 Solid Waste Disposal Regulations

Solid wastes generated from coal preparation are generally subject to land disposal. Although Federal guidelines for land disposal of solid wastes are nonspecific with regard to quantities that can or cannot be disposed of, all facets pertaining to land disposal sites are covered by requirements that the operator conform to the most stringent water quality standards under the provisions of the FWPCA. Leachate collection and treatment systems are required at disposal sites as needed to protect ground and surface water resources.

Provisions of the Solid Waste Disposal Act were significantly modified by the passage on October 21, 1976, of the comprehensive Resource Conservation and Recovery Act (RCRA) of 1976 (P.L. 94-580). Periods ranging from 90 days to 2 years were provided for consummation of many of the actions called for by the Act; hence, details of regulations to be promulated are not yet available. Some of the general provisions of the Act are:

- EPA must issue guidelines within 1 year defining sanitary landfills as the only acceptable land disposal method that can be implemented. Open dumps are to be prohibited.
- Within 1 year EPA shall develop and publish proposed guidelines for solid waste management.
- Within 18 months EPA must propose: criteria for identifying hazardous wastes; regulations for generators of hazardous wastes; regulations for transporters of hazardous wastes; and performance standards for treatment, storage, and disposal of hazardous wastes.

- Permit programs are to be managed by the states under minimum guidelines, which are to be provided by EPA.
- Each regulation promulgated shall be reviewed and, where necessary, revised at least every 3 years.

It has not yet been determined whether coal refuse and combustion ash will be classified as hazardous wastes. Such a classification would require implementation of the most restrictive provisions of the Act.

## 2.2 TECHNICAL STATUS

Coal is a heterogeneous substance containing complex organic molecules as well as inorganic molecules. It contains nearly all of the naturally occurring elements. Some elements of environmental concern that are contained in significant quantities in coal are arsenic, beryllium, cadmium, copper, lead, manganese, mercury, nitrogen, selenium, sulfur, and zinc[1].

Elements of environmental concern may be classified by their tendencies to occur either in the organic coal structure or in the inorganic coal mineral phase. The relative amounts of contaminants and the manner in which they are included in the coal structure vary widely with different coals, thus affecting the degree to which the various contaminants can be removed by coal cleaning processes.

Physical coal cleaning (PCC) processess generally involve crushing run-of-mine coal to a point where some of the mineral impurities are released from the coal structure. The mineral and coal particles are then separated by techniques usually based on differences in the densities or surface properties of the particles.

Chemical coal cleaning (CCC) processes are being developed to provide improved techniques for desulfurizing coals used for steam and metallurgical applications. Chemical coal cleaning processes vary substantially because of the different chemical reactions that can be utilized to remove sulfur and other contaminants. Chemical coal cleaning processes usually involve grinding the coal into small particles with or without chemical

agents at elevated temperatures and pressures. The coal's sulfur is converted into elemental sulfur or sulfur compounds that can be physically removed from the coal structure. Some chemical processes, such as the TRW-Meyers Process, remove only pyritic sulfur. Others, such as the one under development by the Department of Energy (DOE), are said to be capable of removing organic sulfur as well.

Approximately half of all domestically consumed coal is physically cleaned to remove mineral matter and mining residue. A large proportion of metallurgical grade coal is cleaned to remove sulfur, but cleaning operations for steam coal have not previously been designed and operated to remove sulfur for compliance with state and Federal $SO_2$ emission standards. The first steam coal preparation plant designed for such a purpose is nearing completion at Homer City, Pennsylvania. The Tennessee Valley Authority (TVA) is planning two other sulfur-removing plants. None of these steam coal plants incorporates the most advanced beneficiation techniques now used in the metallurgical and mineral industries.

A number of coal cleaning processes are currently under development. These processes are being developed to produce desulfurized coals for use in complying with $SO_2$ emission standards[2]. The Meyers chemical coal cleaning process, which is at an advanced development stage, is being evaluated in a 0.3 Mg/h (1/3 ton/h) test unit at Capistrano, California. At least eight other processes are in various stages of laboratory development. Many of these are reportedly capable of removing organic as well as pyritic sulfur. With accelerated development, several chemical processes could be ready for commercial demonstration within 5 or 10 years.

Coal preparation plants annually generate more than 90 million Tg (100 million ton) of waste. Interaction of air and water in pyrite-rich wastes converts the pyritic sulfur to a dilute sulfuric acid leachate. This leachate may have high concentrations of dissolved trace elements or other potentially

hazardous pollutants[3]. Drainage of the leachate into ground and surface waters may degrade water quality and affect human health. Current knowledge of the relationships between coal mineral properties, coal trace element concentrations, the effects of weathering on the release of trace elements, and the effects of various technologies in controlling trace element pollution is rudimentary.

Coal and mineral dusts generated by handling, transporting, and storing coal may contain high concentrations of hazardous trace elements and compounds. Little is known about the composition of these dusts, their effects on human health, and the degree to which dust emissions can be controlled.

Sludges from coal preparation plants present a disposal problem. Some sludges are not easily dried, and others are thixotropic. Either condition requires containment in a storage pond. Techniques to solidify and dispose of sludge from coal preparation plants are in an early stage of development.

Spent chemicals used in chemical desulfurization contain many potentially hazardous trace elements and compounds. Little is known about the techniques that will be needed to neutralize and dispose of these wastes.

## SECTION 3

## DEVELOPMENT DIRECTIONS

### 3.1 THE MARKET FOR COAL CLEANING

Requirements for control of $SO_2$ pollution have created a primary short-term market for coal cleaning. The degree to which coal cleaning is used to meet these requirements depends upon the specific sulfur emission standards, the desulfurization potential of available coals, the costs of coal cleaning, and the costs of alternative pollution control techniques. Other applications for coal cleaning include the upgrading of subbituminous coals and lignites and the preparation of coals for synthetic fuel conversion processes. The primary emphasis of the interagency coal cleaning program has been on environmental considerations.

The applicability of coal cleaning for compliance with $SO_2$ emission regulations is contingent upon a number of regulatory and technical uncertainties. Once these uncertainties have been resolved, the use of coal cleaning will be defined largely by market considerations (i.e., a determination of the most cost-effective method of coal energy production considering the costs of all pollution control requirements). Near-term applications for compliance with $SO_2$ emission standards are in doubt primarily because of changing regulatory requirements mandated by the 1977 Clean Air Act Amendments. The Amendments require periodic review of emission standards under SIP. Some regulations will be tightened, especially in non-compliance regions and in areas wishing to offset emission increases resulting from industrial growth by reducing emissions from existing boilers.

Proposed revisions of NSPS for utility boilers would require an 85 percent reduction in sulfur between extraction and emission.

This would preclude physical coal cleaning as a sole method for compliance with $SO_2$ emission standards by these boilers. In some instances a combination of coal cleaning and FGD may be more cost-effective than FGD alone. Cases for which this combination may be the most cost-effective strategy cannot be adequately defined because of various uncertanties. The standards have not been promulgated, and the emission averaging time has not been specified. Moreover, some of the potential cost benefits and liabilities associated with coal cleaning have not been quantified. These include (a) the degree to which coal cleaning will reduce coal sulfur variability, (b) the comparable costs for controlling sulfur variability in coal by FGD, and (c) boiler operating and maintenance cost benefits resulting from coal cleaning.

EPA also plans to set BACT standards for industrial boilers. The level at which these standards are set will determine the applicability of coal cleaning as an $SO_2$ emission control strategy in these boilers.

## 3.2 SOME RESEARCH AND DEVELOPMENT OBJECTIVES

Consideration of the above factors along with the current status of coal cleaning technology allows projection of the near- and long-term objectives for coal cleaning research and development.

### 3.2.1 Short-Term Objectives

The short-term objectives of this program are listed as the following:

- Characterization of coal sulfur variability and the degree to which coal preparation attenuates this variability.
- Assessment of the potential of U.S. coals for desulfurization by physical methods, including techniques that rely on surface properties as well as density differences.
- Development of improved fine coal cleaning techniques that will provide for maximum pyrite removal with minimum coal energy losses.

- Development of improved techniques for fine coal dewatering and drying.
- Evaluation of the environmental impacts of coal cleaning.
- Development of technology to control trace elements in leachate from coal preparation plant wastes.
- Determination of the effects of coal cleaning on boiler operating and maintenance costs.
- Establishment of pollution control costs for coal preparation processes.
- Establishment of costs of alternative strategies for compliance with $SO_2$ emission standards by industrial and utility boilers.

### 3.2.2 Long-Term Objectives

The following long-term objectives of this program have been defined:

- Characterization of U.S. coals and their mineral and organic contaminants.
- Development of advanced physical/chemical processes for removing inorganic and organic contaminants from coal.
- Development of techniques for the control of newly regulated pollutants and pollutants from developing coal cleaning technologies.

# SECTION 4

# RESEARCH AND DEVELOPMENT PROGRESS

The interagency coal cleaning program is divided into three major subprograms:

1. Assessment and development of coal cleaning processes;
2. Assessment of environmental impacts from coal cleaning;
3. Development of pollution control technology for coal cleaning processes.

Government organizations participating in the program include the Environmental Protection Agency, the Department of Energy, the Department of Interior, and the Tennessee Valley Authority. The program budget for fiscal 1978 was approximately $8 million. The program is directed for EPA by the Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. Table 1 summarizes projects active during 1977-78 and cites the sections of this report in which they are discussed.

## 4.1 TECHNOLOGY ASSESSMENT AND DEVELOPMENT

Improved techniques for preparation of fine coal are needed to enhance sulfur removal and recovery of energy from coal. The primary objectives of the technology assessment and development activities are to evaluate the potential cleanability of U.S. coals and the performance and costs of commercial equipment that can be used for the beneficiation of fine coal. The program also supports developments of chemical coal cleaning processes and applied research to characterize the basic mechanisms governing beneficiation processes.

## TABLE 1. ACTIVE INTERAGENCY COAL CLEANING PROJECTS

| Project title (contract, grant, or interagency agreement) | Discussed in Section | Organization directing work | Organization performing work | Objectives |
|---|---|---|---|---|
| TECHNOLOGY ASSESSMENT AND DEVELOPMENT | | | | |
| Coal Cleanability IAG-D6-E685 | 4.1.2 | DOE[a] | DOE[a] | Determine desulfurization potential of U.S. coals by size reduction and specific gravity separation. |
| Coal Cleaning Technology Assessment and Development (68-02-2199) | 4.1.3 | EPA | Versar, Inc. | Evaluate performance and costs of equipment for removing sulfur from coal. |
| Interim Support for Homer City Test Program (68-02-2639) | 4.1.4 | EPA/DOE[b] | Chem Systems/ Pennsylvania Electric Co. | Provide test planning and initial test support for the Homer City Coal Cleaning Demonstration Program. |
| Dense-Media Cyclone Pilot Plant (IAG-D6-685) | 4.1.5 | DOE[a]/EPRI/ Penelec/EPA | DOE[a] | Evaluate effects of cyclone design and operation variables on separation of fine coal and pyrite. |
| Demonstration of Coal-Pyrite Flotation (IAG-D6-E685) | 4.1.6 | DOE[a] | Heyl and Patterson Co./Barnes and Tucker Co. | Conduct commercial testing and operation of two-stage coal-pyrite flotation process developed by DOE[a]. |
| Adsorption-Desorption Reactions in Pyrite Flotation (IAG-D6-E685) | 4.1.7 | DOE[a] | University of Utah | Evaluate the adsorption-desorption mechanisms that control performance in the DOE[a] two-stage coal-pyrite flotation process. |
| High-Gradient Magnetic Separation (IAG-D5-E685) | 4.1.8 | DOE[a] | General Electric Co. | Evaluate technical feasibility of high-gradient magnetic separation for removing pyrite from coal. |
| Surface Phenomena in Dewatering of Fine Coal (IAG-D6-E685) | 4.1.9 | DOE[a] | Syracuse University | Evaluate phenomena governing the effectiveness of surfactants in reducing the final moisture content of coal vacuum filter cakes. |
| Reactor Test Project for Chemical Removal of Pyritic Sulfur from Coal (68-0201880) | 4.1.10 | EPA | TRW Defense and Space Systems Group | Evaluate Meyers chemical coal cleaning process in a 1/3 ton/h test reactor unit. |

[a]Department of Energy, Coal Preparation and Analysis Laboratory, Pittsburgh, Pennsylvania

[b]Department of Energy, Office of Environment, Washington, D.C.

(continued)

TABLE 1. (continued)

| Project title (contract, grant, or interagency agreement) | Discussed in Section | Organization directing work | Organization performing work | Objectives |
|---|---|---|---|---|
| Microwave Desulfurization of Coal (68-02-2172) | 4.1.11 | EPA | General Electric | Evaluate the feasibility of coal desulfurization by microwave treatment. |
| Battelle Hydrothermal Process Improvement Studies (68-02-2187) | 4.1.12 | EPA | Battelle Columbus Laboratories | Evaluate methods for liquid/solid separation and leachant regeneration. |
| Coal Cleaning Test Facility | 4.1.13 | DOE[a] | Birtley Engineering Corp. Williams, Trebilocic and Whitehead | Design a DOE coal cleaning test facility. Provide architectural and engineering plans. |
| Coal Preparation Plant Computer Model (IAG-D6-E685) | 4.1.14 | EPA/DOE[a] | DOE[a], University of Pittsburgh, and Battelle | Develop computer model capable of predicting performance of coal preparation plants. |
| Engineering/Economic Analysis of Coal Preparation Operation and Cost (IAF-D6-E685) | 4.1.15 | DOE[a] | Hoffman-Muntner Corp. | Determine costs of cleaning for eight representative coal preparation plants - from jig plants to complex dense-medium plants. |
| Evaluation of Chemical Coal Cleaning Processes (IAG-D5-E685) | 4.1.16 | DOE[c] | Bechtel | Evaluate relative costs and performances of selected chemical coal cleaning processes. |
| Hydrodesulfurization of Coal (68-02-2126) | 4.1.17 | EPA | Institute of Gas Technology | Evaluate desulfurization of coal by mild oxidative treatment followed by devolatilization. |
| Environmental Studies on Coal Cleaning Process (IAG-D5-E721 | 4.1.18 | EPA | Tennessee Valley Authority (TVA) | Evaluate technology for controlling pollution at TVA coal preparation plants. |

[c]Department of Energy, Office of Energy Technology, Washington, D.C.

(continued)

TABLE 1. (continued)

| Project title (contract, grant, or interagency agreement) | Discussed in Section | Organization directing work | Organization performing work | Objectives |
|---|---|---|---|---|
| ENVIRONMENTAL ASSESSMENT | | | | |
| Environmental Assessment of Coal Cleaning Processes (68-02-2163 | 4.2.1 | EPA | Battelle Columbus Laboratories | Evaluate pollution resulting from coal cleaning transportation, and storage. Evaluate coal cleaning as an $SO_2$ emission control technique. |
| Trace Element Characterization of Coal Preparation Wastes (IAG-D5-E681) | 4.2.2 | EPA/DOE[a] | Los Alamos Scientific Laboratory (LASL) | Characterize trace element and mineralogic associations in coal preparation wastes. |
| Trace Elements and Mineral Matter in U.S. Coals (R804403) | 4.2.2 | EPA | Illinois State Geological Survey | Characterize the elemental constituents and mineralogy of U.S. coals. |
| Geology of Contaminants in Coal (IAG-D6-E685) | 4.2.2 | EPA | U.S. Geological Survey | Characterize coal resources west of the Mississippi as to their elemental and mineralogic composition. Evaluate the geological factors that affect or control coal cleanability. |
| A Washability and Analytical Evaluation of Potential Pollution from Trace Elements (IAG-D6-E685 | 4.2.3 | DOE[a] | DOE[a] | Evaluate partitioning of trace elements in 10 U.S. coals during specific-gravity separation. |
| Evaluation of the Effects of Coal Cleaning on Fugitive Elements (IAG-D6-E685) | 4.2.4 | DOE[a] | Bituminous Coal Research, Inc. | Evaluate partitioning of trace elements during preparation and use. |

(continued)

TABLE 1. (continued)

| Project title (contract, grant, or interagency agreement) | Discussed in Section | Organization directing work | Organization performing work | Objectives |
|---|---|---|---|---|
| DEVELOPMENT OF POLLUTION CONTROL TECHNOLOGY | | | | |
| Control of Trace Element Leaching from Coal Preparation Wastes (IAG-D5-E681) | 4.3.1 | EPA/DOE[b] | LASL | Determine leachability of trace elements from coal preparation wastes and evaluate pollution control methods. |
| Control of Blackwater in Coal Preparation Plant Recycle and Discharge (IAG-D5-E685 | 4.3.2 | DOE[a] | Pennsylvania State University | Characterize blackwater generated by coal preparation plants and assess potential potential control methods. |
| Stabilization of Coal Preparation Waste Sludges (IAG-D5-E685) | 4.3.3 | DOE[a] | Dravo Lime | Collect coal preparation plant sludges and perform laboratory stabilization tests. |

### 4.1.1 Assessment of Coal Cleaning as an $SO_2$ Emission Control Technique

Passage of the 1977 Clean Air Act Amendments provides new emphasis for the assessment of coal cleaning as an $SO_2$ emission control technique. New regulatory actions in response to this legislation will significantly change the conditions under which coal cleaning can be used as a method of complying with $SO_2$ emission standards. Studies are in progress to assess the applicability of coal cleaning to reduce $SO_2$ emissions to the required levels in the following regulatory circumstances:

- Existing boilers regulated under SIPs.
- Current Federal NSPS for coal-fired utility boilers.
- Revised NSPS for coal-fired utility boilers.
- NSPS to be promulgated for industrial boilers.

The results of portions of these studies, although preliminary, warrant discussion.

Table 2 summarizes the $SO_2$ emission standards that are expected to be applicable to coal-fired boilers by 1980. Important new mandates by the 1977 Clean Air Act Amendments are requirements for the use of BACT and for a percentage sulfur reduction in addition to an emission limit.

An evaluation of U.S. Bureau of Mines (USBM) data[4] suggests that application of BACT to specific gravity separation, now commonly used for coal de-ashing, can remove 25 to 55 percent of the pyrite from U.S. coals. Moderate reductions in the coal top size and density of separation to correspond to the best current technology would reduce pyrite by 40 to 80 percent. Assuming that all the sulfur remaining in the coal were converted to $SO_2$ upon combustion, burning of these coals would result in $SO_2$ emissions ranging from 0.4 to 1.9 $\mu g$ $SO_2/J$ (0.9 to 4.4 lb $SO_2/10^6$ Btu). Although more pyritic sulfur can be removed at these smaller particle sizes and densities of separation, coal Btu losses would increase to unacceptably high levels unless the high-density sink fractions were upgraded (desulfurized) by further processing.

TABLE 2. $SO_2$ EMISSION STANDARDS FOR COAL-FIRED STEAM GENERATORS

| Application | Sulfur reduction, % | Emission limits, μg $SO_2$/J | Emission limits, lb $SO_2/10^6$ Btu |
|---|---|---|---|
| Existing boilers | | 0.1 - 3.4 | 0.2 - 8.0 |
| Current NSPS for steam generators | | 0.5 | 1.2 |
| Revised NSPS for utility boilers[a] | 85[b] | 0.5 max.<br>0.1 - 0.2 floor | 1.2 max.<br>0.2 - 0.5 floor |
| NSPS for industrial boilers | Unkown | Unknown | Unknown |

[a]Values under consideration.

[b]85% minimum for 24-hour average. A provision of the standard will permit a 75% minimum reduction and an exemption from the 0.5 μg $SO_2$/J level 3 days per month. This provision is to allow for variations in fuel sulfur levels and in performance of pollution control device.

Probable operations would include pulverization, density separation, froth flotation, oil agglomeration, or chemical cleaning. An alternative means of reducing loss of heating value is for the preparation plant to produce multiple product streams to be used in different boilers; high-sulfur coals could be used in boilers with FGD or in boilers subject to less stringent $SO_2$ emission regulations.

If experiments by Min and Wheelock on Iowa coals are applicable to other U.S. coals, the best combination of physical cleaning techniques are potentially capable of removing up to 90 percent of the pyritic sulfur[5]. Combustion of coals cleaned to these levels would produce emissions ranging from 0.3 to 1.5 μg $SO_2$/J (0.8 to 3.5 lb $SO_2/10^6$ Btu).

Chemical coal cleaning processes can remove 95 to 99 percent of the pyritic sulfur and 25 to 40 percent of the coal organic sulfur. Removal of 95 percent of the pyritic sulfur and 25 percent of the organic sulfur from U.S. coals would result in total sulfur reductions in the range of 53 to 77 percent[4].

The sulfur content and sulfur removal potential of coal by physical and chemical techniques vary among coal regions and among coal beds in the same region[6]. Figure 1 presents the estimated energy content of the recoverable Northern Appalachian coal reserves which can be cleaned to meet various $SO_2$ emission levels. Less than five percent of the raw coal is capable of meeting a standard of 0.4 μg $SO_2$/J (1.0 lb $SO_2/10^6$ Btu). Crushing to 10 mm (3/8 inch) and physically cleaning coal at a density of 1.6 or 1.3 $Mg/m^3$ would increase the relative energy content of coals available for compliance with an emission standard of 0.4 μg $SO_2$/J (1.0 lb $SO_2/10^6$ Btu) to approximately 20 percent. Chemical cleaning of appropriate coals by processes that can remove 95 percent of pyritic sulfur and 20 percent of organic sulfur would provide more than $6.5 \times 10^{20}$ J ($6.2 \times 10^{17}$ Btu); i.e., more than 26 percent of the total reserves would be capable of meeting a standard of 0.4 μg $SO_2$/J (1.0 lb $SO_2/10^6$ Btu).

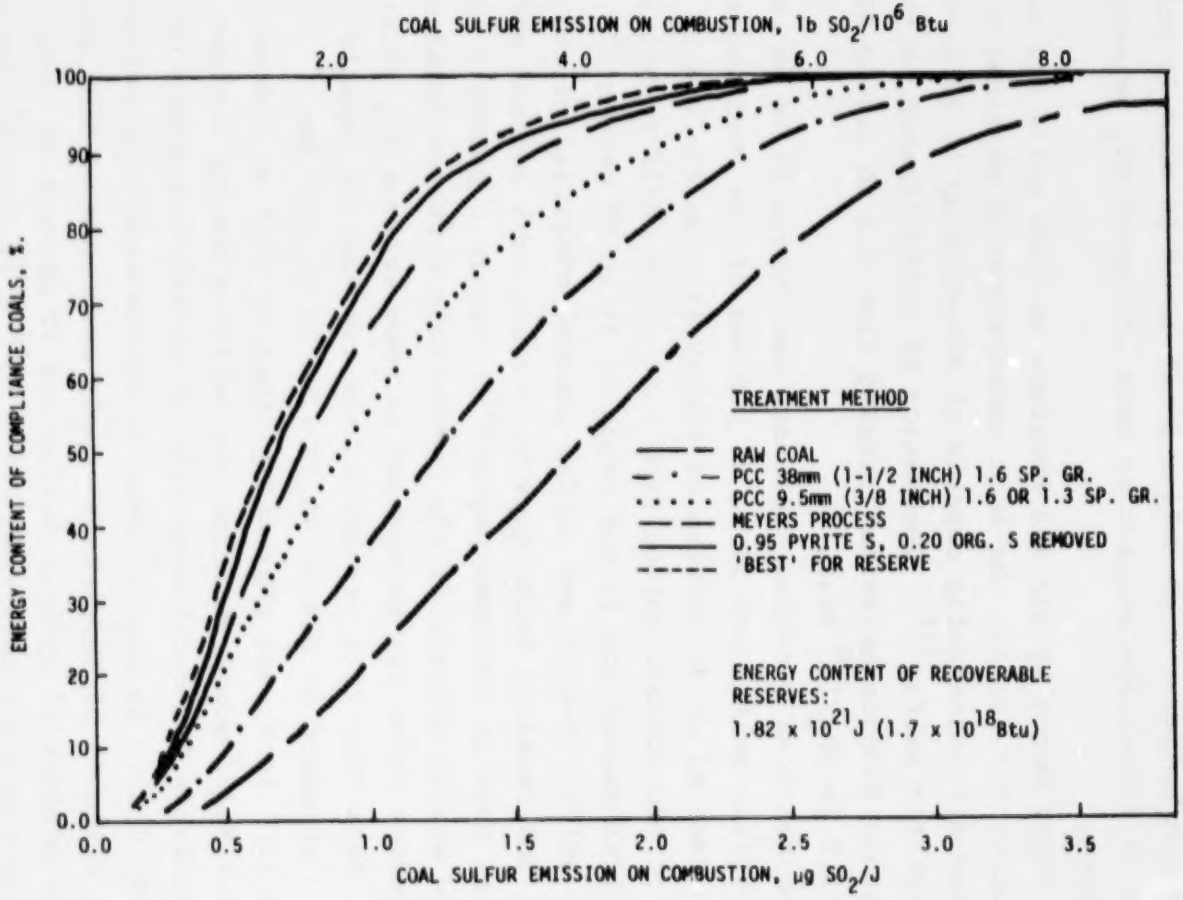



Figure 1. Estimated cleanability of Northern Appalachian coals.

Figure 2 presents similar data on the cleaning potential of U.S. coals. Although Figure 1 and Figure 2 indicate that physical and chemical coal cleaning can be used to provide coals capable of meeting a variety of emission standards, new Federal standards requiring sulfur reductions above about 50 percent would generally preclude the use of physical cleaning as a sole method of complying with $SO_2$ emission standards. Sulfur reduction requirements of 80 percent or more would eliminate the use of chemical coal cleaning as an effective technology for compliance with these standards.

The demand for physical or chemical coal cleaning will depend upon the relative amounts of coals capable of meeting various sulfur emission control standards and the relative costs of other $SO_2$ emission control techniques. In 1975, approximately 423 Tg (467 million ton) of coal were consumed, primarily in utility, industrial, and commercial boilers[7]. Under the National Energy Plan (NEP) coal consumption for these uses and for non-boiler, industrial applications is expected to exceed 958 Tg (1057 million ton) per year in 1985.

In 1975, virtually all coal-burning boilers were subject only to state regulations for existing boilers. Table 3 presents estimates of the 1985 coal consumption by boiler capacity and the emission levels with which each boiler must comply. Even considering that few coals could be desulfurized to levels below 0.5 µg $SO_2$/J (1.2 lb $SO_2/10^6$ Btu), physically cleaned coals could provide complying fuels to meet 79 percent of the projected steam coal demand in 1985 (if a high percentage sulfur removal is not required). These projections are, of course, highly dependent upon impending energy legislation and new emission standards to be promulgated by EPA.

Comparisons of pollution control costs are complex. Factors unique to a given application and site often determine which pollution control option is most cost-effective. Simplified cost comparisons can be made by evaluating the ranges of annual costs for coal cleaning and FGD.

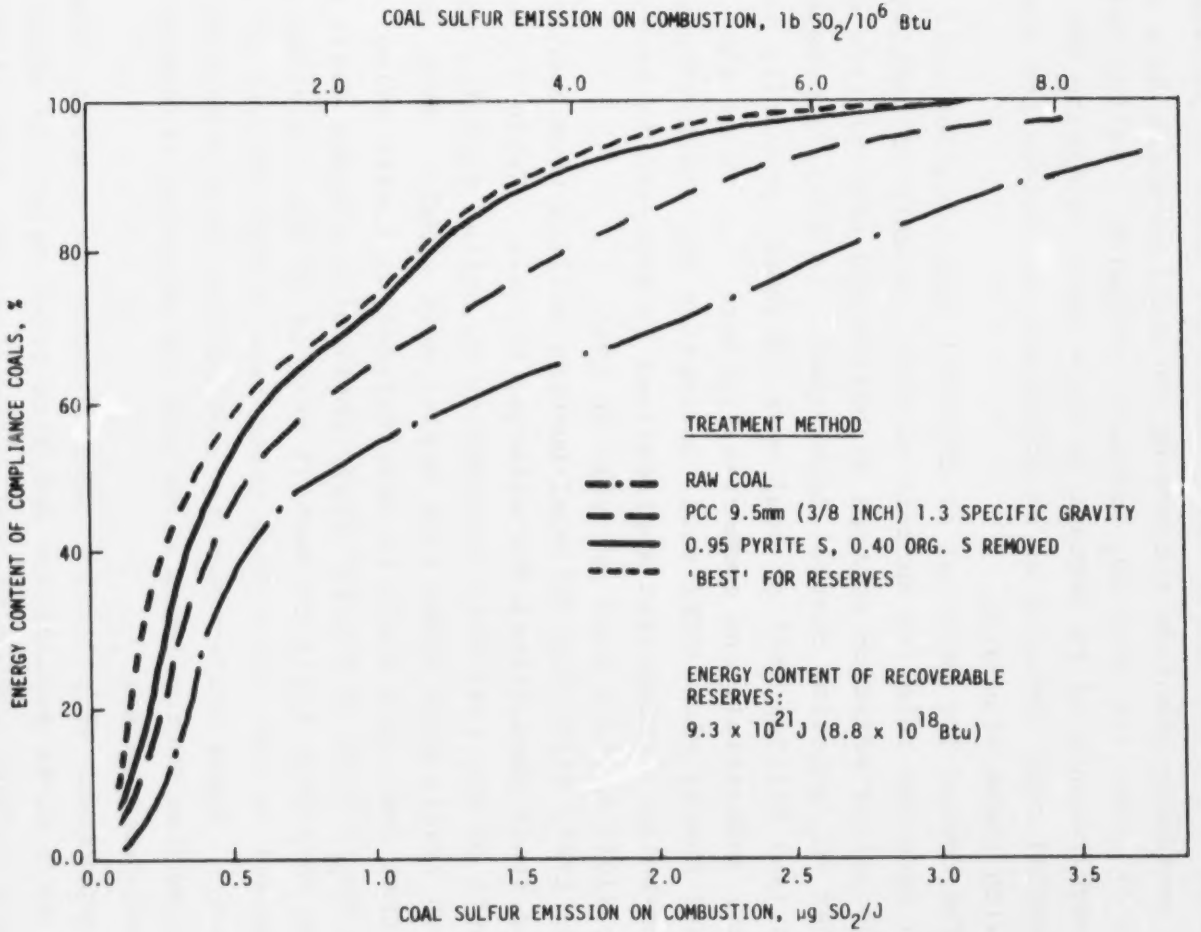



Figure 2. Estimated cleanability of U.S. coals.

TABLE 3. ESTIMATED 1985 COAL CONSUMPTION AND $SO_2$ EMISSION REGULATIONS

| Boiler category | Projected 1985 consumption[a] listed by emission interval, μg $SO_2$/J (lb $SO_2$/$10^6$ Btu) | | | | |
|---|---|---|---|---|---|
| | <0.52 (<1.2) | 0.52 to <0.86 ( 1.2 to <2.0) | 0.86 to <1.72 (2.0 to <4.0) | >1.72 (>4.0) | Total |
| Utility | 204[b] | 403 | 113 | 59 | 779 |
| Industrial and commercial[c,d] | 14 | 203 | 52 | 9 | 278 |
| Total | 218 | 606 | 165 | 68 | 1057 |

[a]Projected total 1985 consumption corresponding to NEP (million short tons, approximately equivalent to Tg).

[b]One-third utility boilers constructed after 1975 are assumed to comply with revised NSPS of 0.21 to 0.34 $SO_2$/J (0.48 to 0.8 lb $SO_2$/$10^6$ Btu). Two thirds of all new utility boilers constructed after 1975 are assumed to comply.

[c]The distribution of use for all categories of existing boilers is assumed to comply as follows: <0.52 μg $SO_2$/J (<1.2 lb $SO_2$/$10^6$ Btu), 20%; 0.52 to <0.86, (1.2 to <1.48), 35%; 0.86 to <1.72, (1.48 to <4.0), 30%; ≥1.72 (>4.0), 15%.

[d]All new industrial and commercial boilers are assumed to comply with emission standards of 0.64 to 0.86 μg $SO_2$/J (1.48 to 2.0 lb $SO_2$/$10^6$ Btu).

Utility and industrial FGD systems now in use have demonstrated $SO_2$ removal efficiencies that exceed 90 percent[8,9,10]. FGD costs are sensitive to the type of FGD system, boiler capacity, boiler capacity factor, and level of desulfurization required. Annual FGD costs increase with decreasing boiler capacity factor, and increasing sulfur removal.

Annual coal cleaning costs are sensitive to plant capacity, plant complexity, and coal replacement costs. Coal replacement costs are defined as the costs of coal energy that must be discarded with the plant residue (carbon and mineral matter). Plant complexity increases with the number of different process operations involved.

Figure 3 presents estimates of cost ranges for annualized $SO_2$ and particulate control costs for PCC, CCC, and FGD. Particulate control costs of \$0.095/GJ (\$0.10/$10^6$ Btu) are included so that the costs of coal cleaning can be compared with the costs of FGD, which include costs for particulate control. An analysis of the cost ranges in Figure 3 and of the desulfurization potential of physical and chemical cleaning indicates the following:

1. Where technically feasible and where a low percentage sulfur extraction is satisfactory for meeting the emissions regulations, cost savings can be realized by the use of PCC for coals fired in utility and industrial boilers, especially small boilers with low capacity factors.
2. PCC probably cannot be used to meet revised NSPS for utility boilers, unless it is used in combination with FGD.
3. Where a high $SO_2$ removal efficiency is required, FGD appears to be more competitive than CCC, especially in the case of large base-load utility boilers. CCC could possibly be used in a cost-effective manner in small industrial boilers with low capacity factors.
4. The most probable use of CCC is in combination with PCC to yield lower sulfur levels than are available by PCC.

In some cases, under current state and Federal standards, the $SO_2$ control costs of using FGD in combination with PCC may be lower than those for using FGD alone[11]. Studies comparing

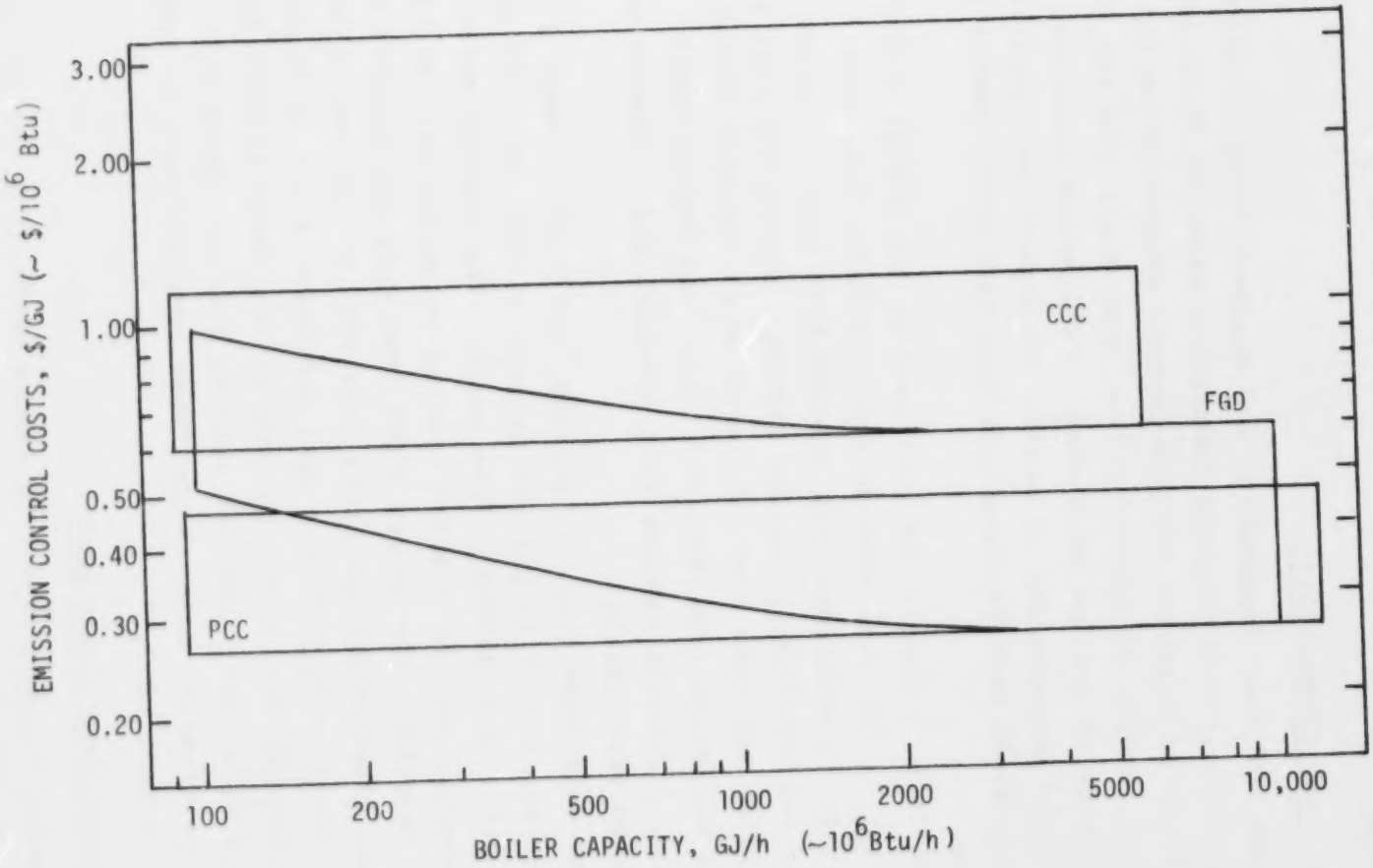



Figure 3. Annualized costs of $SO_2$ and particulate Control.

the costs of a combination of PCC and FGD with those of FGD alone in meeting a standard of 80 to 90 percent sulfur removal are not complete.

### 4.1.2 Coal Cleanability

The DOE Coal Preparation and Analysis Group at Bruceton, Pennsylvania, is continuing laboratory experiments to determine the effect of crushing and gravimetric separation on the liberation and removal of pyritic sulfur from coals from the principal coal fields of the United States. Information generated from this study is necessary to assess the impact that physical coal cleaning would have on emissions from stationary combustion sources.

In 1976, a report was published on the sulfur reduction potential of 455 coal samples from six major U.S. coal fields[6]. Since then an additional 220 samples have been collected from the Western and Appalachian Region States. During the past year washability analyses were completed on 31 raw coal channel samples collected from Maryland, Ohio, and Pennsylvania. In addition, 4 lignite samples from Arkansas and 7 lignite samples from Texas were tested.

The data show that, on average, the lignite samples contained 15.9 percent ash, 0.23 percent pyritic sulfur, and 1.09 percent total sulfur on a moisture-free basis. The average moisture was 30.9 percent, and the average heating value was 24.1 MJ/kg (10,377 Btu/lb). The survey shows that only two samples from Arkansas, those which contained less than 0.7 percent organic sulfur, could be upgraded to meet the NSPS of 0.5 μg $SO_2$/J (1.2 lb $SO_2/10^6$ Btu). All but one of the Texas lignite samples contained more than 1 percent sulfur; however, since most of this sulfur was organic, none of the Texas samples could be upgraded to meet current NSPS.

### 4.1.3 Technology Assessment

A major 3-year project to assess technology for physical and chemical desulfurization of coal began in January 1977. The

project is being conducted by Versar, Inc., with the assistance of Joy Manufacturing Company's Denver Equipment Division. The program includes six major technical tasks:

1. Collection of existing data on sulfur removal by physical coal cleaning equipment.
2. Generation of new data and evaluation of physical coal cleaning technology for sulfur removal.
3. Evaluation of equipment for fine coal dewatering and handling.
4. Assessment of coal preparation requirements for synthetic fuel conversion processes.
5. Performance of studies of physical coal preparation processes to evaluate the trade-offs between sulfur removal and costs.
6. Evaluation of chemical coal cleaning processes.

The task methodology includes literature and field surveys, compilation of data from many representative sources (Bureau of Mines and other governmental organizations carrying out research in the field, industrial research facilities, and commercial sources), testing and evaluation of currently operational equipment, and cost evaluation of various processes.

More than 55 percent of the coal used in the United States is subjected to PCC. The degree of cleaning varies widely, and the process technologies range from simple mechanical removal of rock and dirt to operation of complex coal benefication plants for removal of heavier contaminants and noncombustible minerals. At the present time, however, most plants are designed primarily for removal of ash and not for removal of pyrite from coal. Sophisticated systems for recovering fines and pyrite are still under development. Versar has extensively reviewed various physical coal cleaning processes ranging from established technologies such as hammermills, crushers, and jigs to recent developments and variations of the dense-medium cyclone and the application of froth flotation to coal cleaning. The processes are summarized in Table 4.

TABLE 4. SUMMARY OF PHYSICAL COAL CLEANING UNIT OPERATIONS

| Unit operation | Description | Remarks |
|---|---|---|
| Jigging | A pulsating fluid stratifies coal particles in increasing density from top to bottom. The cleaned coal overflows at the top. | Most popular and least expensive coal washer available, but may not give accurate separation. Sizes: 3.4 to 76 mm (6 mesh to 1 in.) |
| Tables | Pulverized coal and water are floated over a table shaken with a reciprocating motion; lighter coal particles are separated to the bottom of the table, while heavier, larger, impure particles move to the sides. | Sizes: 0.15 to 6.4 mm (100 mesh to 1/4 in.) |
| Dense-medium | Coal is slurried in a medium with a specific gravity close to that at which separation is to be made; lighter, purer coal floats to the top and is continously skimmed off. | Advantages: ability to make sharp separation at any specific gravity within the range normally required; ability to handle wide range of sizes; relatively low capital and operating costs relative to high capacity and small space requirements; ability to handle fluctuations in feed quantity and quality. Sizes: 0.59 to 200 mm (28 mesh to 8 in.) |
| Hydrocyclones | The separating mechanism is described as taking place in the ascending vortex. The high and low specific gravity particles moving upward in this current are subjected to centrifugal forces effecting separation. | If maximum pyrite reduction and maximum clean coal yield are to be obtained, supplemental processes such as cyclone classifying, fine-mesh screening and froth flotation are necessary (on-stream process). Hydrocyclones presently are used in the U.S. to clean flotation-sized coal, but can be used for coal as coarse as 64 x 0 mm (1/4 x 0 in.) |

(continued)

TABLE 4. (continued)

| Unit operation | Description | Remarks |
|---|---|---|
| Humphrey spiral | Coal-water slurry is fed into a spiral conduit. As it flows downward stratification of the solids occurs with the heavier particles concentrated in a band along the spiral. An adjustable splitter separates the stream into two products - a clean coal and the middlings. | Has shown significant ash and sulfur reduction on 0.42 x 0 mm (35 x 0 mesh) Middle Kittanning coal. |
| Launder-type washers | Raw coal is fed into the high end of a trough with a stream of water. As the stream of coal and water flows down the incline, particles having the highest settling rate settle into the lower strata of the stream. These are the middling or refuse particles. The clean coal particles gravitate into the upper strata before separation. | Three types of launders are recognized based on mode of transport. Sizes: 4.76 to 76 mm (4 mesh to 3 in.) |
| Pneumatic | Coal and refuse particles are stratified by means of pulsating air. The layer of refuse formed travels forward into pockets or wells from which it is withdrawn. The upper layer of coal travels over the refuse and is removed at the opposite end. | Most acceptable preparation method from the standpoint of delivered heating value cost. Sizes: up to 6.4 mm (1/4 in.) |

(continued)

TABLE 4. (continued)

| Unit operation | Description | Remarks |
|---|---|---|
| Froth flotation | A coal slurry is mixed with a collector to make certain fractions of the mixture hydrophilic. A frother is added and finely disseminated air bubbles are passed through the mix. Air-adhering particles are floated to the top of the remaining slurry, and are then removed as a concentrate. | Froth flotation is used to reduce pyrite in English coals; the flotation of coal refuse to obtain salable pyrite is uneconomical in view of today's poor sulfur market; if ethyl xanthate is used as the collector, it is aborbed into coal pyrite in such a manner as to make it ineffective for flotation. Sizes: 1.17 to 0.044 mm (14 to 325 mesh) |
| Two-stage flotation for pyrite | Experimental coal flotation process in which the coal is floated while high-ash impurities are rejected. The froth concentrate is then repulped in $H_2O$, treated with an organic colloid to depress the coal. A xanthate collector and alcohol frother are added and then refloated. | Frothing agent is methylisobutyl carbinol; pH regulators are NaOH and HCl. Coal depressant is Aero depressant 633. Pyrite flotation collector is potassium amyl xanthate. In general the ratio of readily floatable coal to total floatable coal increases with an increase in fixed carbon content. Therefore, increased rank yields an increased ratio. |

An evaluation of current chemical coal cleaning processes has also been completed. Twenty-nine different processes were reviewed, eleven of which were selected for comparative evaluations. Estimated annual operating costs for the eleven processes (including the cost of coal, calculated at $23/Mg ($25/ton) ranged from $36/Mg ($40/ton) to $60/Mg ($66/ton). Chemical coal cleaning processes are still under development, however, and none of the processes has been tested in a unit larger than 8 Mg/day (9 ton/day). Consequently, performance and cost comparisons are relatively uncertain. The CCC processes vary substantially because of the many possible reaction mechanisms and chemicals that can be used to remove sulfur and other reactive impurities from coal. Most chemical processes reportedly remove 90 percent of the pyritic sulfur, and several remove up to 40 percent of the organic sulfur as well.

The major chemical coal cleaning processes exhibit a great deal of diversity with respect to such variables as kinds and amounts of sulfur removed, type of coal successfully desulfurized, degree of coal crushing and grinding prior to chemical processing, state of process development, process chemistry, major process steps, and prospects for technical and economic success.

The various processes are summarized in the following tables. Table 5 gives details of the 11 major processes with respect to some of the above variables. Table 6 lists process costs and performance, and Table 7 itemizes costs for each process. The chemical coal cleaning processes are summarized in Table 8.

Versar also includes an extensive discussion of current process technology for fine coal dewatering and drying. Fine coal is produced in the various mining operations and is also a major by-product of physical coal cleaning, which is accomplished almost exclusively by wet processes. It has been estimated that for each percent of water in coal, approximately 29 kJ/kg (25,000 Btu/ton) is required to evaporate that moisture.

TABLE 5. SUMMARY OF COAL CLEANING PROCESSES

| Process and sponsor | Method | Type sulfur removed | Stage of development | Problems | Annual operating costs, $/Mg clean coal ($/ton)[a] |
|---|---|---|---|---|---|
| "Magnex" Hazen Research, Inc., Golden, Colorado | Dry pulverized coal treated with $Fe(CO_5)$ causes pyrite to become magnetic. It is then removed magnetically | Up to 90% pyritic | Bench and 91 kg/day (200 lb/day) pilot plant operated | Disposal of S-containing residues; continuous recycle of CO to produce $Fe(CO_5)$ requires demonstration | 44.8 (40.7) |
| "Syracuse" Syracuse Research Corp., Syracuse, N.Y. | Coal is comminuted by exposure to $NH_3$ vapor; conventional physical cleaning separates coal/ash | 50-70% pyritic | Bench scale | Disposal of sulfur-containing residues | 43.4 (39.5) |
| "Meyers" TRW, Inc., Redondo Beach, Calif. | Oxidative leaching using $Fe_2(SO_4)_3$ oxygen in water | 90-95% pyritic | 8 Mg (9 ton)/day for reaction system; lab or bench scale for other process steps | Disposal of acidic $FeSO_4$ & $CaSO_4$ in extraction step requires demonstration | 47.9 (43.4) |
| "LOL" Kennecott Copper Co., Ledgemont, Ma. | Oxidative leaching using $O_2$ and water at moderate temp. and pressure | 90-95% pyritic | Bench scale | Disposal of gypsum sludge; acid corrosion of reactors | 50.9 (45.3) |
| "ERDA" (PERC), Bruceton, Pa. | Air oxidation and water leaching at high temperature and pressure | 95% pyritic; up to 40 % organic | Bench scale 11 kg day (25 lb/day) continuous unit under construction | Gypsum sludge disposal; acid corrosion at high temperatures | 56.9 (51.6) |

[a]Value shown includes cost of raw coal at $27.5/Mg ($25/ton)

(continued)

TABLE 5. (continued)

| Process and sponsor | Method | Type sulfur removed | Stage of development | Problems | Annual operating costs, $/Mg clean coal ($/ton)[a] |
|---|---|---|---|---|---|
| "GE" General Electric Co., | Microwave treatment of coal permeated with NaOH solution converts sulfur forms into soluble sulfides | 75% total S | Bench scale | Process conditions not established; caustic regeneration process not established | 44.3 (40.2) |
| "Battelle" Battelle-Columbus, Ohio | Mixed alkali leaching | 95% pyritic; 25-50% organic | 9 kg/hr (20 lb/hr) pilot plant and bench scale | closed loop regeneration process unproven; residual sodium in coal | 62.0 (56.1) |
| "JPL" Jet Propulsion Laboratory, Pasadena, Calif. | Chlorinolysis in organic solvent | 90% pyritic; up to 70% organic | Lab scale, proceeding to bench and mini pilot plant | Environmental problems; conversion of HCl to $Cl_2$ not established | 50.3 (45.9) |
| "IGT" Institute of Gas Technology, Chicago, | Oxidative pretreatment followed by hydrodesulfurization at 800°C | 95% pyritic; up to 85% organic | Lab and bench | Low Btu yield (55%); change of coal matrix | 72.4 (65.7) |
| "KVB" KVB, Inc. Tustin, Calif. | Sulfur oxidezed in $NO_2$-containing atmoshere; sulfates washed out | 95% pyritic; up to 40% organic | Laboratory | Disposal of waste and possibly heavy metals; possible explosion hazard via dry oxidation | 53.8 (48.8) |
| "ARCO" Atlantic Richfield Co., Harvey, Ill. | Not given | 95% pyritic; Some organic | Continuous 0.45 kg/hr (1 lb/hr) bench-scale unit | Unknown | 51-64 (46-58) estimated |

TABLE 6. PROCESS PERFORMANCE AND COSTS OF MAJOR COAL CLEANING PROCESSES

| | Processes that remove pyritic sulfur only | | | | |
|---|---|---|---|---|---|
| | Feed[a] | TRW | LOL | Magnex | Syracuse + PCC |
| Net coal yield, Tg/day (ton/day)[b] | 7110 (7840) | 6400 (7056) | 6400 (7056) | 5645 (6225) | 6915 (6271) |
| Sulfur, % | 1.93 | 0.83 | 0.83 | 0.97 | 1.50 |
| Heating value, MJ/kg (Btu/lb) | 28.5 (12300) | 29.7 (12835) | 29.7 (12835) | 28.9 (12400) | 33.9 (14600) |
| Emission rate μg $SO_2$/J (lb $SO_2$/$10^6$ Btu) | 1.33 (3.1) | 0.56 (1.3) | 0.56 (1.3) | 0.69 (1.6) | 0.90 (2.1) |
| Btu recovery, % | | 94 | 94 | 80 | 95 |
| Costs | | | | | |
| Capital, million $ | | 109 | 114.1 | 37.8 | 50.4 |
| Annual, million $ | | 37.2 | 45.3 | 19.2 | 17.6 |
| $/Mg of clean coal ($/annual ton)[c] | | 47.9 (43.4) | 50.6 (46.9) | 44.8 (40.7) | 43.4 (39.5) |
| S/GJ[c] (S/$10^6$ Btu)[c] | | 0.72 (1.69) | 0.78 (1.82) | 0.70 (1.64) | 0.58 (1.35) |

[a]Pittsburgh seam coal from Pennsylvania, which contains 1.22 weight percent pyritic sulfur, 0.01 weight percent sulfate, and 0.70 weight percent organic sulfur. Heating value of 28 MJ/kg (12,300 Btu/lb) is assumed.

[b]All values reported on moisture-free basis.

[c]Includes coal costs at $27.6/Mg ($25/ton).

(continued)

TABLE 6. (continued)

| | Processes that remove pyritic and organic sulfur | | | | | | |
|---|---|---|---|---|---|---|---|
| | ERDA | GE | Battelle | JPL | IGT | KVB | ARCO |
| Net coal yield, Tg/day (tons/day)[b] | 6400 (7056) | 6826 (7526) | 6755 (7448) | 6470 (7155) | 4270 (4704) | 6070 (6690) | 6400 (7056) |
| Sulfur, % | 0.65 | 0.5 | 0.65 | 0.6 | 0.55 | 0.61 | 0.69 |
| Heating value, MJ/kg (Btu/lb) | 29.7 (12835) | 28.5 (12300) | 26.4 (11350) | 28.5 12300) | 27.2 (11685) | 30.6 (13120) | 28.9 (12400) |
| Emission rate, μg $SO_2$/J (lb $SO_2$/$10^6$ Btu) | 0.4 (0.9) | 0.35 (0.8) | 0.52 (1.2) | 0.4 (1.0) | 0.39 (0.9) | 0.39 (0.9) | 0.47 (1.1) |
| Btu recovery, % | 94 | 96 | 88 | 91 | 57 | 91 | 91 |
| Costs | | | | | | | |
| Capital, million $ | 166.8 | 102.0 | 168.1 | 103.0 | 134.6 | 67 | |
| Annual, million $ | 56.6 | 35.9 | 74.8 | 44.3 | 38.1 | 44.0 | 58.7 |
| $/Mg of clean coal ($/annual ton)[c] | 56.9 (51.6) | 44.3 (40.2) | 62.0 (56.1) | 50.3 (45.9) | 72.4 (65.7) | 53.8 (48.8) | |
| $/GJ[c] ($/$10^6$ Btu)[c] | 0.86 (2.00) | 0.70 (1.63) | 1.06 (2.46) | 0.80 (1.87) | 1.21 (2.81) | 0.80 (1.86) | |

TABLE 7. OPERATING COSTS OF MAJOR CHEMICAL COAL CLEANING PROCESSES

| | GE | | Battelle | | JPL | | IGT | | KVB | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal |
| Labor and G&A | 1830 | 0.8 | 2100 | 0.93 | 3700 | 1.71 | 4925 | 3.45 | 1445 | 0.72 |
| Amortization | 11980 | 5.3 | 19700 | 8.72 | 6900 | 3.2 | 15600 | 11.1 | 7870 | 3.9 |
| Taxes and Insurance | 3790 | 1.65 | 5000 | 2.21 | 1400 | 0.64 | 4050 | 2.86 | 2010 | 0.99 |
| Maintenance and supplies | 5310 | 2.33 | 17800 | 7.88 | 2300 | 1.06 | 6732 | 4.7 | 3350 | 1.65 |
| Utilities | 7170 | 3.13 | 23100 | 10.2 | 1400 | 0.64 | 3300 | 2.31 | 17271 | 8.5 |
| Chemicals | 5860 | 2.56 | 7100 | 3.14 | 28600 | 13.3 | 3300 | 2.2 | 11909 | 5.87 |
| Waste disposal | | | | | | | | | 131 | 0.07 |
| Annual processing cost | 35900 | 15.7 | 74800 | 33.1 | 44300 | 20.5 | 38107 | 26.73 | 43987 | 21.7 |
| Raw coal | 66000 | 28.9 | 66000 | 29.3 | 66000 | 30.5 | 66000 | 46.5 | 66000 | 32.6 |
| Total | 101900 | 44.7 | 140800 | 62.3 | 110300 | 51.0 | 103707 | 73.0 | 109987 | 54.3 |

(continued)

TABLE 7. (continued)

| | Meyers | | Ledgemont | | Magnex | | Syracuse | | ERDA | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal | $1000 | $/Mg clean coal |
| Labor and G&A | 3962 | 1.84 | 1600 | 0.74 | 786 | 0.42 | 620 | 0.28 | 3255 | 1.22 |
| Amortization | 12820 | 5.98 | 13400 | 6.3 | 4444 | 2.35 | 5919 | 3.1 | 19600 | 9.2 |
| Taxes and insurance | 3270 | 1.53 | 3400 | 1.6 | 1135 | 0.6 | 2016 | 1.1 | 5004 | 2.3 |
| Maintenance supplies | 5460 | 2.54 | 7300 | 3.41 | 1891 | 1.0 | 3780 | 1.97 | 8340 | 3.9 |
| Utilities | 5764 | 2.7 | 10600 | 4.95 | 1400 | 0.74 | 1040 | 0.54 | 13224 | 6.2 |
| Chemicals | 4692 | 2.2 | 8200 | 3.83 | 9144 | 4.84 | 4220 | 2.21 | 6932 | 3.24 |
| Waste disposal | 1275 | 0.6 | 800 | 0.37 | 498 | 0.23 | -- | -- | 240 | 0.11 |
| Annual processing costs | 37243 | 17.4 | 45300 | 21.18 | 19218 | 10.2 | 17592 | 9.25 | 56595 | 26.5 |
| Raw coal | 66000 | 30.9 | 66000 | 30.9 | 66000 | 35.0 | 66000 | 34.7 | 66000 | 30.9 |
| Total | 103243 | 48.3 | 111399 | 52.05 | 85238 | 45.2 | 83595 | 44.0 | 122595 | 57.3 |

TABLE 8. COST-EFFECTIVENESS AND OTHER CHARACTERISTICS OF CHEMICAL COAL CLEANING PROCESSES

| Process | Type of sulfur removed | Sulfur[b] in product, % | Sulfur removed, % | Process Costs, $/Mg including cost of coal | Cost-effectiveness, $/% S removed | Cost-effectiveness ranking | Meets EPA NSPS | Probable success, %, based on available information | Time to commercial availability, years[c] |
|---|---|---|---|---|---|---|---|---|---|
| Magnex | P[a] | 0.97 | 0.96 | 44.8 | 46.6 | 3 | No | 85 | 2 - 3 |
| Syracuse and physical cleaning | P | 1.50[d] | 0.43 | 43.4 | 100 | 4 | No | 70 | 2 - 3 |
| TRW | P | 0.83 | 1.10 | 47.9 | 43.5 | 1 | No | 90 | 3 |
| LOL | P | 0.83 | 1.10 | 50.6 | 46.0 | 2 | No | 50 | 4 - 5 |
| ERDA | PO[a] | 0.65 | 1.28 | 56.9 | 44.5 | 4 | Yes | 70 | 5 |
| GE | PO | 0.50 | 1.43 | 44.3 | 31.0 | 1 | Yes | 60 | 5 |
| Battelle | PO | 0.65 | 1.28 | 62.0 | 48.4 | 5 | Yes | 35 | 4 - 5 |
| JPL | PO | 0.60 | 1.33 | 50.3 | 37.8 | 2 | Yes | 55 | 5 |
| IGT | PO | 0.55 | 1.38 | 72.4 | 52.5 | 6 | Yes | 20 | 5 |
| KVB | PO | 0.68 | 1.25 | 53.8 | 43.0 | 3 | Yes | 10[e] | 5 |
| ARCO | PO | 0.69 | 1.24 | f | f | f | Yes | f | f |

[a]P-pyritic; PO-pyritic and organic.

[b]Based on Pittsburgn seam coal from Pennsylvania which contains 1.22 weight percent pyritic, 0.01 percent sulfate, and 0.70 percent organic sulfur.

[c]Time frame assumes continuing effort or renewed effort starting immediately.

[d]80 percent yeild of product assumed in cleaning plant.

[e]Processes not currently active, partially accounting for low probability of success.

[f]Insufficient data available to permit educated guess.

Ancillary problems related to high moisture content are caking, freezing, and increased transport costs. Moisture reduction, however, also creates hazards, since dry fine coal requires special handling techniques to prevent dust pollution and explosions. Fortunately, technology is currently available for meeting the problems associated with handling dry, fine coal.

Mechanical dewatering devices can be grouped into two categories:

1. Those that do not produce a final product - hydrocyclones and static thickeners.
2. Those that produce a final product - screens, centrifuges, spiral classifiers and filters.

Coal dryers also are of two types:

1. Direct heat, in which the products of combustion make direct contact with the coal.
2. Indirect heat, in which the products of combustion do not make direct contact with the coal.

Table 9 summarizes the moisture ranges in product coal that can be achieved by various moisture reduction systems, assuming a coal top size of 10 mm (3/8 in).

TABLE 9. TYPICAL MOISTURE CONTENT OF PRODUCTS BY EQUIPMENT OR PROCESS

| Type of equipment/process | Percent moisture in discharge product |
|---|---|
| Dewatering screens | 8 to 20 |
| Centrifuges | 10 to 20 |
| Filters | 20 to 50 |
| Hydraulic cyclones | 40 to 60 |
| Static thickeners | 60 to 70 |
| Thermal dryers | 6 to 7.5 |
| Oil agglomeration processes | 8 to 12 |

The problems of fine coal processing, dewatering, drying, and handling are not new, and established technology seems to be capable of meeting the needs created by the increasing volume of fine coal. The most important element to be determined is the economics associated with dewatering the fines as necessary for a high degree of sulfur removal.

Versar has also reported on coal slurry sampling and coal preparation requirements for synthetic fuel conversion processes.

### 4.1.4 Homer City Coal Cleaning Plant

An advanced coal cleaning pilot plant is under construction near the Homer City Generating Station Power Complex in Homer City, Pennsylvania (Figure 4). The coal preparation facility is jointly owned by Pennsylvania Electric Company (Penelec - a subsidiary of General Public Utilities Corporation), and New York State Electric & Gas Corp. The facility will process 4.7 Tg (5.2 million ton) of run-of-mine (ROM) coal per year, with a design capacity of 1.1 Gg/h (1200 ton/h). The plant has four distinct process circuits: coarse coal, medium coal, fine coal, and fine coal scavanging. Unique design features of the Homer City plant include:

1. Selective crushing to maximize the amount of 6 mm by 0.149 mm (1/4 inch x 100 mesh) coal.
2. Use of small diameter (0.35 m) dense-medium cyclones to process the 2 mm by 0.149 mm (9 x 100 mesh) size fractions.
3. Computerized control of the magnetite slurry density.

The major purpose of the plant is to clean coal for compliance with $SO_2$ emission standards. As is shown in Table 10, the plant is expected to produce medium- and low-sulfur coals. The medium-sulfur coal will be used in the two existing 600-MW generating units to meet a Pennsylvania emission standard of 1.7 µg $SO_2$/J (4.0 lb $SO_2/10^6$ Btu). The low-sulfur coal will be used in a new 650-MW unit to meet Federal NSPS of 0.5 µg $SO_2$/J (1.2 lb $SO_2/10^6$ Btu).

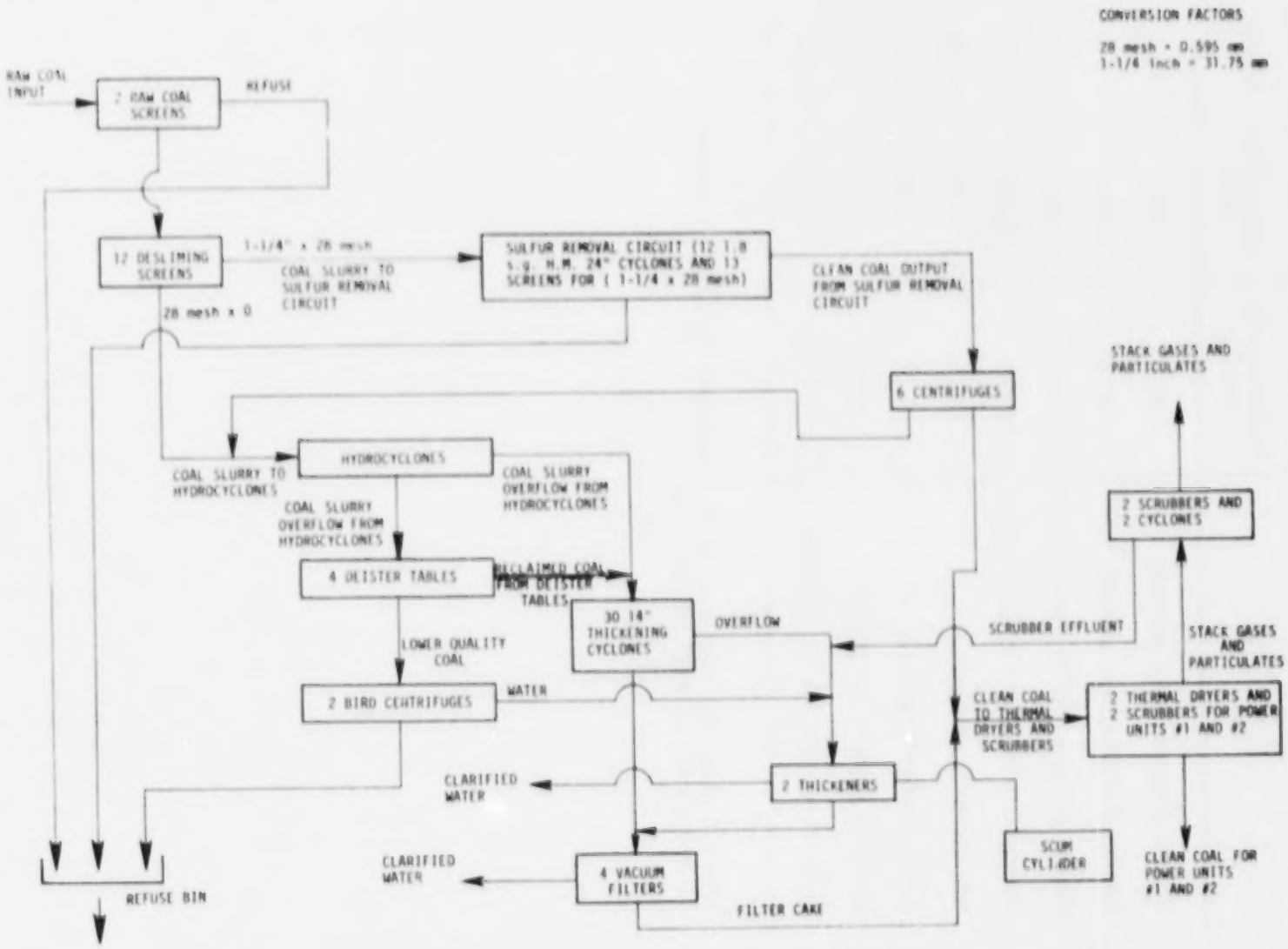

CONVERSION FACTORS
28 mesh = 0.595 mm
1-1/4 inch = 31.75 mm
RAW COAL INPUT
2 RAW COAL SCREENS
REFUSE
12 DESLIMING SCREENS
1-1/4" x 28 mesh
COAL SLURRY TO SULFUR REMOVAL CIRCUIT
SULFUR REMOVAL CIRCUIT (12 1.8 s.g. H.M. 24" CYCLONES AND 13 SCREENS FOR ( 1-1/4 x 28 mesh)
CLEAN COAL OUTPUT FROM SULFUR REMOVAL CIRCUIT
28 mesh x 0
6 CENTRIFUGES
STACK GASES AND PARTICULATES
HYDROCYCLONES
COAL SLURRY TO HYDROCYCLONES
COAL SLURRY OVERFLOW FROM HYDROCYCLONES
2 SCRUBBERS AND 2 CYCLONES
COAL SLURRY OVERFLOW FROM HYDRGCYCLONES
4 DEISTER TABLES
RECLAIMED COAL FROM DEISTER TABLES
30 14" THICKENING CYCLONES
OVERFLOW
SCRUBBER EFFLUENT
STACK GASES AND PARTICULATES
LOWER QUALITY COAL
2 BIRD CENTRIFUGES
WATER
CLEAN COAL TO THERMAL DRYERS AND SCRUBBERS
2 THERMAL DRYERS AND 2 SCRUBBERS FOR POWER UNITS #1 AND #2
CLARIFIED WATER
2 THICKENERS
SCUM CYLINDER
CLARIFIED WATER
4 VACUUM FILTERS
CLEAN COAL FOR POWER UNITS #1 AND #2
REFUSE BIN
FILTER CAKE

Figure 4. Preliminary block flow diagram for Homer City Coal Cleaning Plant in its interim configuration

TABLE 10. HOMER CITY PLANT PRODUCT SPECIFICATIONS

| | Medium-sulfur coal | Low-sulfur coal | Refuse |
|---|---|---|---|
| Weight distribution, percent | 56.2 | 24.7 | 19.1 |
| Energy distribution, percent[a] | 61.6 | 32.9 | 5.5 |
| Energy content, MJ/kg (dry basis) | 29.2 | 35.4 | 7.8 |
| Energy content, Btu/lb (dry basis) | 12,549 | 15,200 | 3,367 |
| Ash content, percent | 17.75 | 2.84 | 69.69 |
| Sulfur content, percent | 2.24 | 0.88 | 6.15 |
| Emission factor, ng $SO_2$/J | 1.53 | 0.49 | 15.7 |
| Emission factor, lb $SO_2$/$10^6$ Btu | 3.57 | 1.16 | 36.54 |

[a]Overall plant Btu recovery is 94.5 percent, including 1 percent allowance for thermal drying loss.

EPA, Penelec, DOE, and the Electric Power Research Institute (EPRI) are providing cooperative support to a 3-year test project at the Homer City complex with the following objectives:

1. To determine the variability of sulfur and other pollutants in coal fed to the cleaning plant.
2. To determine the performance of equipment used for separation of coal and pyrite.
3. To determine the capability of plant process controls to maintain the coal product streams within specifications for sulfur, ash, and Btu content.
4. To characterize pollutant streams emitted from the preparation and power plants.
5. To determine the need for development of improved pollution control technology.
6. To evaluate the effects of using clean coal on the performance of boilers and electrostatic precipitators at the power plant.
7. To determine capital and operating costs of the preparation plants, i.e., the costs of using physical coal cleaning to meet $SO_2$ emission standards.

The preparation plant is scheduled for construction in two phases. The first phase, completed in October 1977, is capable of cleaning coal to meet an emission standard of 1.8 μg $SO_2$/J (4.0 lb $SO_2/10^6$ Btu). It was shut down during the UMW strike and remained closed to facilitate construction of the second phase of the plant. The complete plant was scheduled to begin operations in the fall of 1978.

Acceptance tests on the first-phase operation were completed in 1977. Operation of the equipment and plant was near design expectations. The average sulfur emission level of the clean coal over the 3-day acceptance test period was 1.01 μg $SO_2$/J (2.24 lb $SO_2/10^6$ Btu). The acceptance test results are summarized in Table 11.

Tests are now being conducted to establish performance characteristics of the electrostatic precipitator and boiler while the power plant boilers are burning uncleaned coal. Preparation plant performance tests and power plant operating evaluations are scheduled to begin late 1978 or early 1979.

TABLE 11. HOMER CITY PLANT, PHASE-ONE ACCEPTANCE TESTS RESULTS (MOISTURE FREE BASIS)

| | Ash, % | Total sulfur, % | Heating value | | Emission level | |
|---|---|---|---|---|---|---|
| | | | kJ/kg | Btu/lb | $\mu g\ SO_2/J$ | $lb_6\ SO_2/10^6\ Btu$ |
| Feed coal | 20.05 | 2.33 | 14.2 | 12,239 | 1.64 | 3.82 |
| Clean coal | 13.05 | 1.51 | 15.7 | 13,527 | 0.96 | 2.24 |
| Refuse | 76.85 | 5.37 | 3.1 | 2,646 | 17.55 | 40.81 |

Average Btu recovery: 97.80%

Average yield: 85.50%

Average sulfur removal: 41.36%

### 4.1.5 Dense-Medium Cyclone Pilot Plant

Deep cleaning of medium-sulfur coal is one alternative strategy for meeting the $SO_2$ NSPS. The Homer City preparation plant is the first to employ this process. Washing the coal at a density of 1.27 $Mg/m^3$ produces a sharp, efficient separation of large amounts of near-density material.

DOE is conducting a test program of a pilot-scale dense-medium cyclone at Bruceton, Pennsylvania. This program is being conducted in cooperation with EPA, EPRI, and the owners of the Homer City plant.

The objectives of the test program are to determine and optimize the performance of the dense-medium cyclones for fine coal cleaning, and hence to evaluate the performance of the dense-medium cyclones in the Homer City plant. The pilot plant has been designed and constructed, and all necessary equipment has been installed. Several shakedown tests were run in order to check plant operation and to establish procedures for sample collection, processing, and analysis. A 12-month test program is planned to evaluate the effects of several variables on the performance of the dense-medium cyclone. These variables include medium-to-coal ratio, inlet pressure, orifice size, magnetite grade and size distribution, medium additives, and viscosity.

### 4.1.6 Coal/Pyrite Flotation Circuit Demonstration

Froth flotation[12] is used commercially to separate coal and mineral matter. It is one of the most specific of the separation processes, based on sensitive surface properties of the individual minerals. Briefly, conditions are arranged so that when a pulp is agitated and air bubbles are blown through it, coal pyrite particles attach themselves to the bubbles, and are floated out in a froth, which is skimmed off.

The surface property of interest is the surface energy, or surface tension, manifest in what is more readily recognized as wettability. Chemicals are added to the slurry of coal and pyrite to facilitate the attachment of coal pyrite to the air

bubbles. Collectors are added to physisorb or chemisorb onto the coal pyrite surface and affect the wettability. Regulators or conditioners are added to the slurry to maintain the pH within a critical region. Activators and depressors are added to render a surface more or less amenable to the action of a collector. Frothers are added to insure the formation of a stable froth with sufficient buoyancy to carry the load of floatable coal pyrite out of the slurry.

Unfortunately, the surface properties of some coal and pyrite particles are not sufficiently dissimilar to permit efficient separation. In some cases, multiple stages of flotation and proper combinations of reagents result in a separation[13,14]. In other cases, the coal does not appear to be amenable to coal/pyrite separation by flotation. However, the DOE is developing a flotation process especially for coal/pyrite separation. The process consists of a first stage flotation step to remove coarse, free pyrite and other refuse and a second stage in which clean coal froth concentrate is repulped and treated with a coal depressant, a pyrite collector, and a frother to selectively float the remaining pyrite. Under a cooperative agreement between Barnes and Tucker Company and the DOE, a two-stage coal/pyrite flotation circuit has been installed in the Lancashire No. 25 preparation plant. It was completed in September 1977 and a 1-year test program was started at the termination of the UMW strike.

### 4.1.7 Adsorption/Desorption Reactions in the Desulfurization of Coal by a Pyrite Flotation Technique

A study of adsorption/desorption reactions occurring in the desulfurization of coal by the DOE two-stage flotation process (see section 4.1.6) has been completed by the University of Utah[15]. This research has provided information concerning the process of adsorption on coal of various organic depressants. It has been shown that this adsorption is physical rather than chemical and that the depressant cannot be removed by repeated washing.

Laboratory flotation tests demonstrated that the first-stage coal flotation response is sensitive to the residual concentration of the second-stage coal depressant (Aero Depressant 633) in the recycled water. It was shown, however, that repeated contact with fresh coal removes much of the residual depressant from the water; this suggests that the contact of recirculated water with fresh coal and refuse in a preparation plant might remove most of the residual depressant.

Study of the second stage of the process showed that the second-stage pyrite collector (potassium amyl xanthate) chemisorbs onto the surface of the pyrite, and that the reaction effectively goes to completion. In addition, it was demonstrated that the coal/pyrite flotation response with amyl xanthate differs significantly from that of ore pyrite. Consumption of the pyrite collector is about an order of magnitude greater by coal pyrite than by ore pyrite. The reason for the high amyl xanthate requirement for coal pyrite flotation appears to be related to surface heterogeneities in the marcasite component of the coal pyrite, particularly clay inclusions, which contribute significantly to its hydrophilic character.

### 4.1.8 High-Gradient Magnetic Separation of Coal and Pyrite

High-gradient magnetic separation (HGMS) is a practical, new technique for separating small, weakly magnetic particles on a large scale. This technology, used commercially in the purification of kaolin clay, was investigated by General Electric Company with the objective of establishing the technical feasibility of removing a substantial fraction of the inorganic sulfur from dry coal powders at significant processing rates.

In work performed under the initial contract, only marginal desulfurization in air streams was observed. Because of the poor performance of the dry separator system, a 2-month funded extension was granted to obtain supplemental data that would indicate why the earlier results were unsatisfactory and how they might be improved.

The earlier tests were performed by injecting pulverized coal into a relatively high-velocity air stream, which then passed through a high-gradient magnetic separator. The resulting poor separations were thought to be due to agglomeration of coal and mineral particles. The researchers observed that the separation was marginally better when the fines were removed and hypothesized that the fines promoted agglomeration. It was also suspected that there might be significant turbulent flow in the neighborhood of individual matrix fibers which could result in large viscous forces on the particles and would make the retention of trapped particles on the matrix very difficult. Electrostatic forces did not appear to be significant factors.

In dry separation tests carried out in the supplementary program, the use of an air stream to propel the coal through the matrix was abandoned. Instead, the coal was moved by gravity feed assisted by a combination of mechanical and electromagnetic vibration. The coal used in most of the tests was taken from the same batch (0.25 mm [60 mesh] top size, Upper Freeport) used in the earlier series of tests; some freshly mined coal was also tested for comparison. In addition to the dry tests, some wet separations were performed. The tests were conducted with relatively small feed samples (approximately 20 grams in the dry tests and 80 grams in the wet tests). In addition to using 0.25 mm by 0 feed, some of the material was separated into plus and minus 0.07 mm (200 mesh) size fractions and tested separately.

The results of these tests on dry coal led to the following conclusions:

1. Dry magnetic separation by HGMS is feasible if the coal fines are first removed and if a suitable technique is used for gravity feed.
2. Multiple passes may be desirable to increase coal recovery (only single passes were taken in this work).
3. Pyrite removal by HGMS from oxidized and from freshly mined coals is substantially the same.

### 4.1.9 Surface Phenomena in the Dewatering of Coal

Fine coal handled or cleaned in slurry form is dewatered to render it suitable for conveying and blending, to reduce the cost of transporting it, and to increase its effective calorific value. The removal of water from coal finer than 0.6 mm (28 mesh) is difficult and expensive. Vacuum filters are relatively economical and practical for dewatering coal in the minus 0.6 mm (28 mesh) size range, but the product usually contains over 20 percent moisture. As a result, thermal drying is often required to reduce the moisture content of the filter cake to acceptable levels. Thermal dryers, however, are costly to install and operate, are hazardous, and are a source of air pollution.

The purpose of this investigation, which is being carried out under a DOE contract with Syracuse University, is to study the dewatering of coal and to expand the knowledge of water-coal separation. Through a clear understanding of the effects of the molecular and ionic nature of various surfactants on the coal-water interface and on the air-water interface, one should expect to be able to improve dewatering process.

The activity of surfactants in effecting moisture reduction in coal dewatering is usually characterized by the surface tension of the water. This investigation indicates, however, that the reduction in filter cake moisture content with addition of surfactant to the coal slurry may be due not only to a change in surface tension at the air-water interface but also to changes in surface energies at the solid-liquid and solid-air interfaces. Therefore, surface tension is not a unique criterion for predicting the dewatering behavior of surfactant solutions. Test data show, for example, that it takes the adsorption of six layers of a nonionic surfactant at a surface tension of $3.09 \times 10^{-2}$ N/m to slightly surpass the final water content of coal achieved with the adsorption of a monolayer of an anionic surfactant at a surface tension of $4.07 \times 10^{-2}$ N/m. The data further show that the successful use of surfactants to promote dewatering in coal

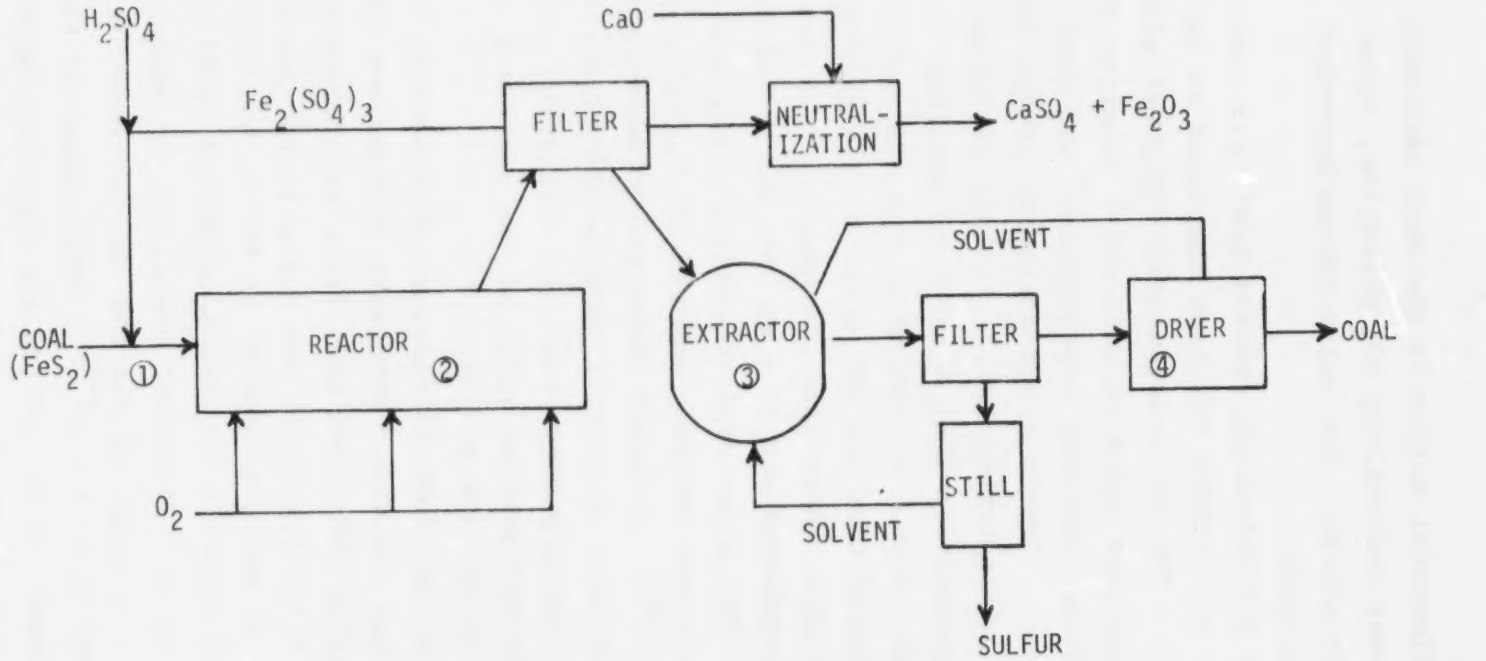
preparation plants will depend on control of the surfactant concentration in the slurry. If micelles form on the coal surface because of a large concentration of surfactant in the slurry and if their structure incorporates large quantities of water, then an increase in water retention would result.

### 4.1.10 Reactor Test Project for Chemical Removal of Pyritic Sulfur from Coal

In previous years EPA supported bench- and laboratory-scale development work on coal desulfurization by aqueous ferric salt leaching[16,17]. This process, the Meyers Process, which has been developed by TRW, has now advanced to the pilot plant stage.

The process chemically removes essentially all of the pyritic sulfur from coal through a mild, oxidative treatment. Important pollutant trace elements such as lead, cadmium, and arsenic are removed at the same time. The process is particularly cost-effective for providing compliance coal for industrial boilers and smaller electric utilities, and for recovering and desulfurizing coal fines rejected from mining and washing operations.

The Meyers chemical coal cleaning process is shown schematically in Figure 5. Coal is mixed with an aqueous solution of ferric sulfate (Step 1), previously extracted from coal, to form a slurry. The slurry's temperature is then raised to 100° to 130°C (Step 2), and the ferric sulfate oxidizes the pyritic sulfur in the coal to form elemental sulfur and a mixed iron sulfate. At the same time oxygen or air is introduced to regenerate the reacted ferric sulfate. Ferric sulfate dissolves into the leach solution, while the elemental sulfur is removed in a solvent extraction step (Step 3). The coal is dried, and the solvent is recovered (Step 4). The products of the process are elemental sulfur and iron sulfate, which may be limed to give a dry gypsum and iron oxide material. Trace elements from the coal are rejected from the leach solution with the stabilized gypsum-




REACTOR CONDITIONS

TEMPERATURE: 110° - 132°C (230° - 270°F)

PRESSURE: 260 - 550 $kN/m^2$ gauge (30 - 80 psig)

RESIDENCE TIME: 5 - 8 hours

PARTICLE SIZE: 1.19 mm (14 mesh)

Figure 5. Meyers Process flow sheet.

iron oxide solid. Elemental sulfur is the most desirable product obtainable in processes controlling $SO_2$ pollution, since it may be marketed or easily stored. The solid gypsum byproduct is reported safe and storable.

Construction of a pilot-scale reactor test unit (RTU) with a capacity of 0.3 Mg/h (1/3 ton/h) has been completed at Capistrano, California (Figure 6). The RTU incorporates equipment with which to evaluate the key process steps of coal-leach solution slurry formation, coal leaching, leachant regeneration, and coal leachant filtration (separation). Checkout and shakedown of the RTU was completed at the end of September 1977. Initial performance tests were made on Appalachian Coal donated by American Electric Power from its Martinka mine. Operation of the plant through January 1978 demonstrated that the RTU could be run continuously in three-shift operations. More than 254 hours of RTU test operation have been completed and 22.5 Mg (49,700 lb) of coal have been processed. The input coal containing 1 percent inorganic sulfur was continuously and reliably reduced to a pyritic sulfur level of 0.16 percent[18]. Although there was no measurable coal loss, calculations indicate an overall process efficiency of 93 to 96 percent, including process heat and electrical energy requirements. The average heating value of the processed coal was increased by 814 kJ/kg (350 Btu/lb).

The test unit was shut down in February 1978 because of corrosion in the primary reactor. Extensive evaluations using erosion-corrosion coupons indicated that fiber-reinforced plastics, elastomers, and 316L stainless steel are suitable for leach solution/coal service at temperatures up to 90° C, but that 316L stainless steel is not suitable for the more severe conditions encountered in the reactor. Titanium, Hastelloy, or rubber-lined brick over mild steel are required for the reactor-regenerator service at temperatures up to 130°C[18]. Replacement of the reactor vessel and resumption of testing are dependent upon a possible transfer of project management to DOE. Meanwhile, bench-scale tests are continuing in order to evaluate a process modification called Gravichem.

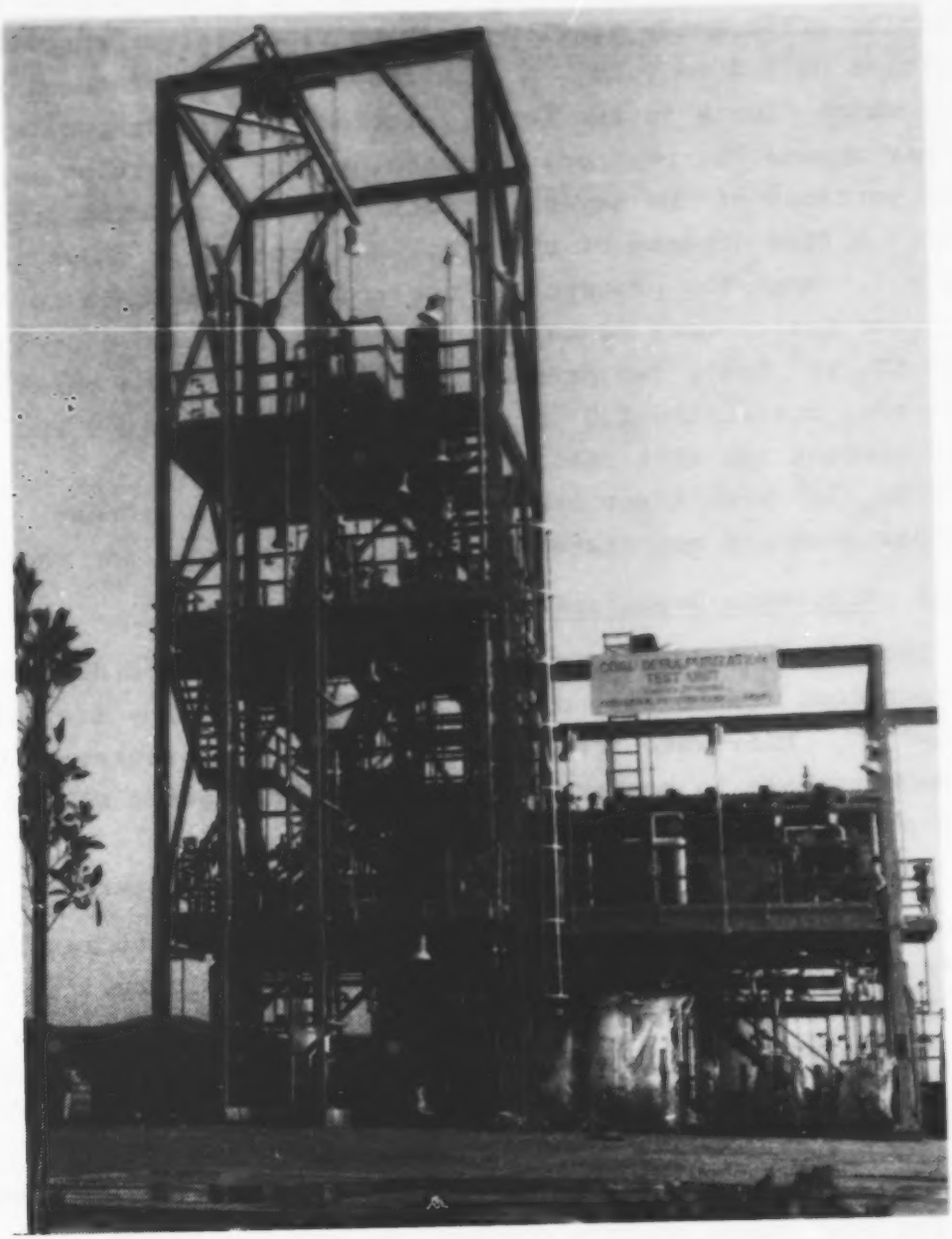


Figure 6. Reactor test unit - Meyers Process Capistrano, California.

Bench-scale experimentation showed that the iron sulfate-sulfuric acid leach solution can be used as a homogeneous dense medium to efficiently gravity-separate fine coal at specific gravities of 1.2 to 1.35. A significant portion of the input coal, which floats in the leach solution, is almost pyrite-free and may bypass the reactor, elemental sulfur extraction, and dryer portions of the Meyers Process, thereby reducing process costs. A flow diagram of the Gravichem process is shown in Figure 7. When the process was applied at bench-scale to a TVA (Interior Basin) coal containing 12 percent ash and 3 μg $SO_2$/J (7 lb $SO_2/10^6$ Btu), two products were obtained: a 4 percent ash float coal containing 1.3 μg $SO_2$/J (3 lb $SO_2/10^6$ Btu), and an 11-12 percent ash sink coal containing 2 μg $SO_2$/J (4 lb $SO_2/10^6$ Btu) after treatment by the Meyers Process. Both of these products met state $SO_2$ emission standards for the coal.

### 4.1.11 Microwave Desulfurization of Coal

Laboratory experiments by General Electric have demonstrated the technical feasibility of coal desulfurization by microwave energy[19]. Microwave irradiation of an aqueous slurry of coal and NaOH appears to convert both pyritic and organic sulfur into water-soluble sulfides ($Na_2S$, $Na_2S_x$).

The basic steps of the desulfurization process are:

1. Pulverize coal to 0.6 to 0.15 mm (28 to 100 mesh).
2. Mix with solution to produce a thick slurry.
3. Partially dry the slurry.
4. Subject to microwave irradiation for periods of 30 to 60 seconds at 1 atmosphere pressure (nitrogen atmosphere).
5. Wash coal and dry for use.
6. Convert sulfides to elemental sulfur and recover.

The last step, sulfide conversion, may involve the use of carbon dioxide either generated by a limestone calciner or directly from the stack gases. The carbon dioxide converts the sulfides to sodium carbonate and hydrogen sulfide. The carbonate is then treated with lime to regenerate the sodium hydroxide, although this step has not yet been demonstrated practically.

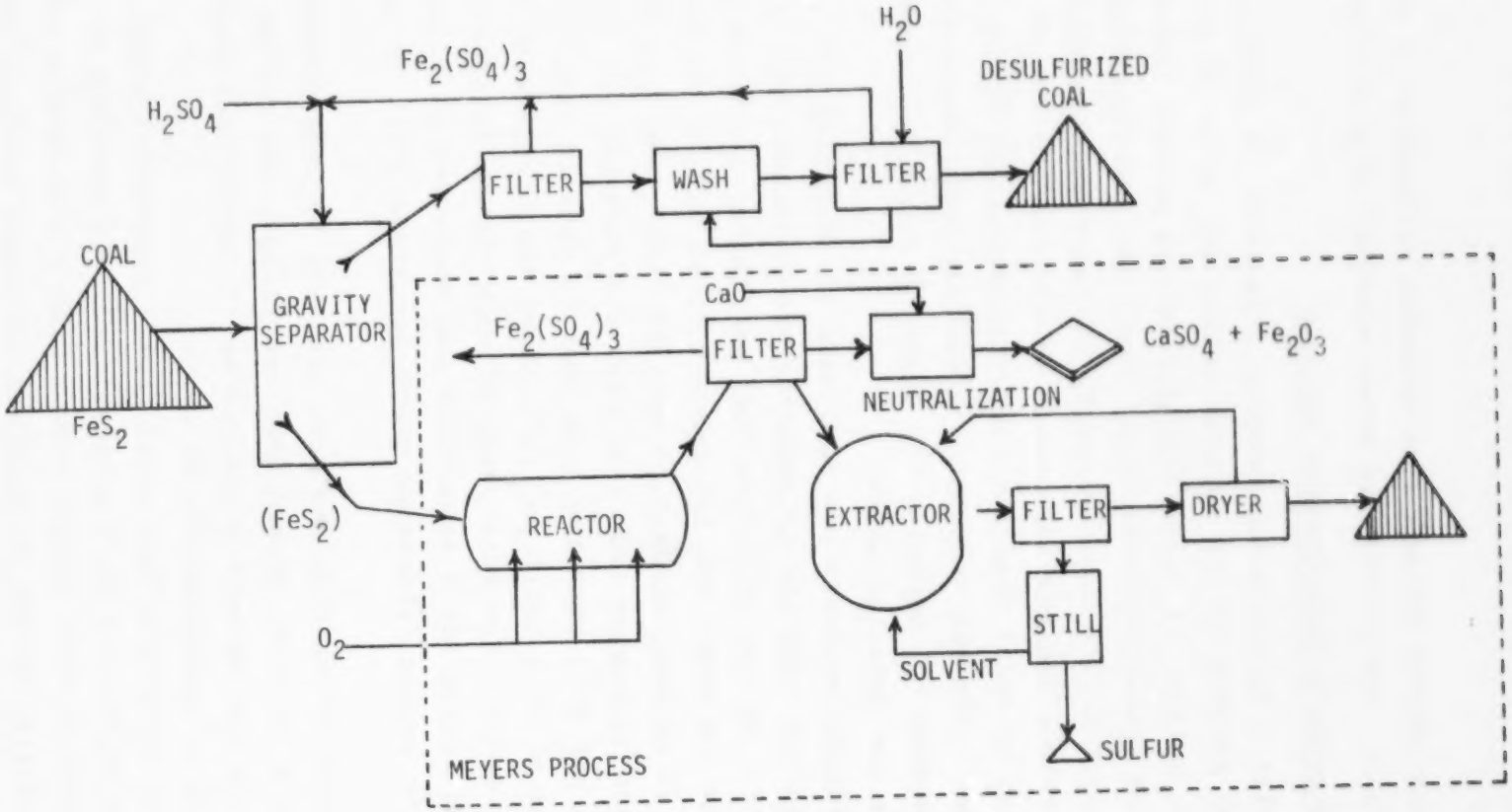



Figure 7. Gravichem Process flow sheet.

Further review including an economic evaluation is given in section 4.1.3. The process is shown schematically in Figure 8.

4.1.12 Battelle's Hydrothermal Process

Battelle's hydrothermal process (Figure 9) is capable of removing 95 percent of the pyritic sulfur and up to 40 percent of the organic sulfur. A large fraction of the process costs results from operations that occur after the reaction step converts the pyritic and organic sulfur to water-soluble sulfides. These operations include separation of liquids and solids, regeneration of spent leachant, and dewatering and drying of the product coal. EPA has supported laboratory experiments to evaluate methods for reducing the costs of these unit operations. The results are detailed below.

Significant progress has been made in improving the liquid/solid separation rate and in reducing the moisture content of the coal product. By use of larger coal particles, i.e., 100 percent minus 0.8 mm (20 mesh) and 100 percent minus 0.3 mm (50 mesh) instead of 70 percent minus 0.07 mm (200 mesh), the filtration rate has been increased from less than 0.3 Mg/h per $m^2$ (0.03 ton/h per $ft^2$) with the fine coal to greater than 5.8 Mg/h per $m^2$ (0.6 ton/h per $ft^2$) after the fourth wash with the coarser coals. For this phase of work vacuum filtration was employed and liquid/solid separation was conducted at 70°C. Normally, the vacuum filtration cakes contained about 50 percent solids.

Additional dewatering has been achieved by centrifugation. Using a 0.15 m (6 inch) screen bowl centrifuge, the solids content of the 100 percent minus 0.8 mm (20 mesh) coal product was increased to approximately 60 percent.

From the results of the liquid/solid separation study, a near-optimum washing circuit was designed. It consists of (1) a washing circuit of four rotary vacuum disc filter stages and five vacuum belt filter stages to separate the spent leachant from the desulfurized coal, and (2) a screen bowl centrifuge stage to

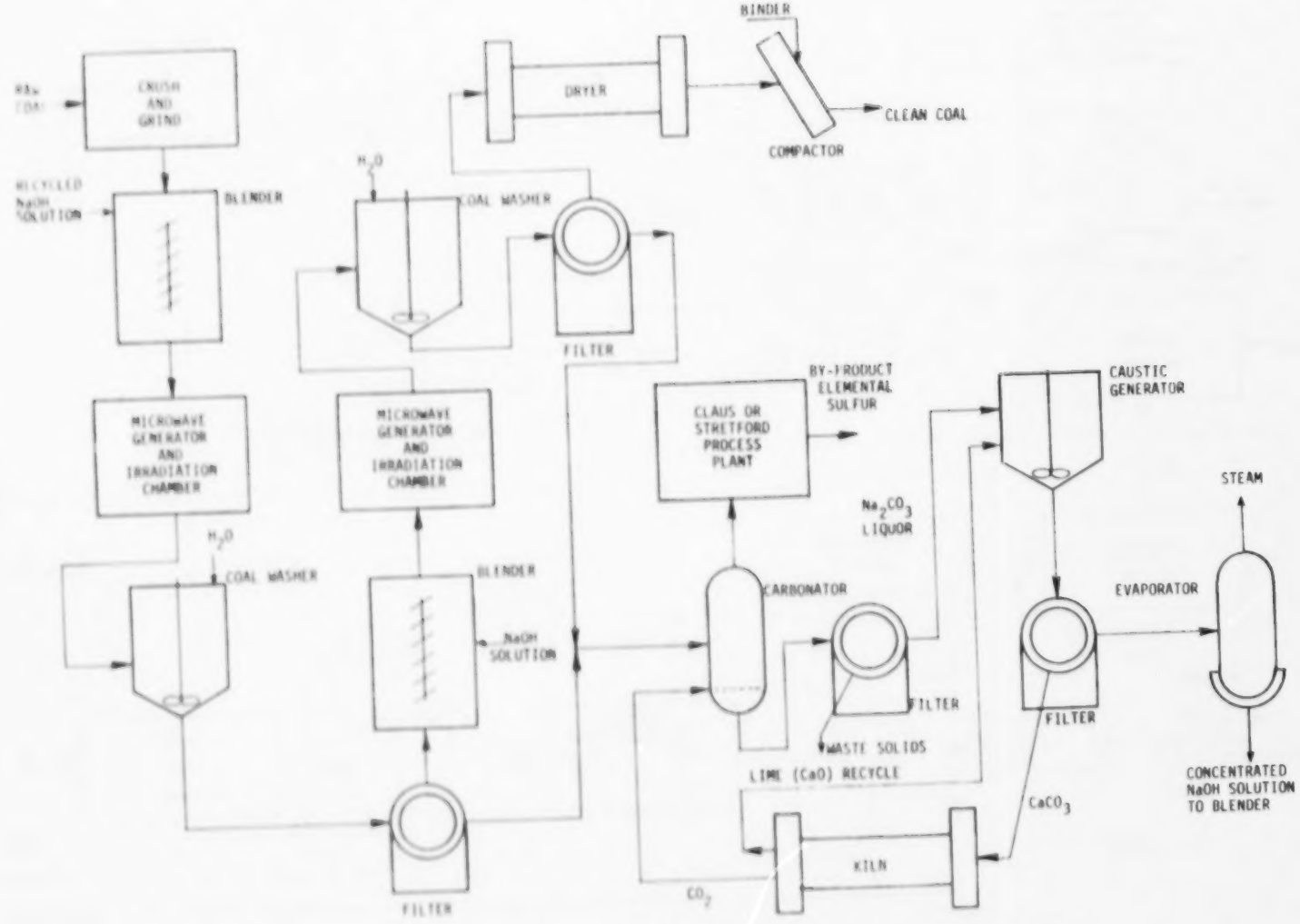



Figure 8. General Electric Microwave Process flow sheet.

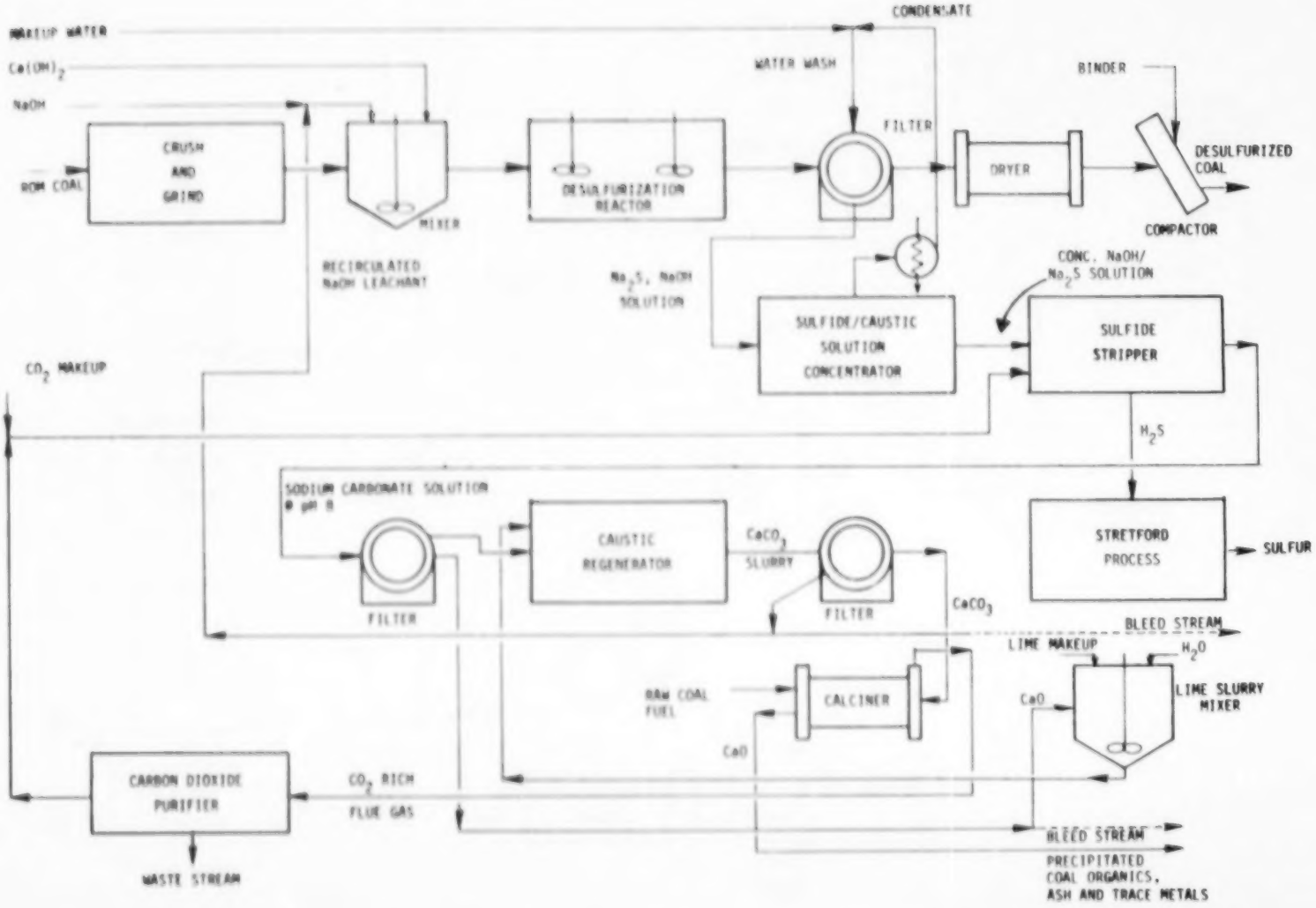



Figure 9. Battelle Hydrothermal Process flow sheet.

dewater the coal product. Countercurrent washing would be employed, using a saturated lime solution in the last stage to reduce the sodium to an acceptable level at a water-to-coal ratio of 1.5 to 1.75. These process improvements reduce the cost of chemical coal cleaning by alkali leaching.

In desulfurization of coal using alkali, the sulfur in the coal reacts with the alkaline leachant to form sodium sulfide ($Na_2S$). The $Na_2S$, being water-soluble, is separated from the coal as discussed above. In commercial practice, the resulting spent leachant would be recycled after removal of the sulfide sulfur.

Among the materials that have been screened as potential candidates for regeneration of the spent leachant for recycle are: (a) zinc compounds such as zinc oxide and sodium zincate, (b) iron compounds such as ferric and ferrous hydroxides, ferric and ferrous carbonates, and (c) activated carbon.

The leading candidate at present is ferrous carbonate. At an Fe/S ratio of about 3, approximately 88 percent of the total sulfur is separated from spent leachant. Ferrous carbonate does not contaminate the regenerated leachant with foreign anions or cations and yields a regenerated leachant for recycle. Although other compounds are also effective, the sulfide sulfur removal efficiency depends on the method employed to produce the iron compounds, and some of the compounds cannot be easily regenerated for recycle.

### 4.1.13 Coal Cleaning Test Facility

The physical coal cleaning research of DOE is widely recognized for its depth and general applicability to the needs of industry; however, the program has been hampered by the lack of an available integrated preparation pilot plant facility in the United States. Such a facility is needed so that technology or equipment developed by DOE can be demonstrated to industrial representatives in a fully integrated coal preparation plant. Unbiased engineering data then could be readily scaled up to

operation of a full-size commercial coal preparation plant. Moreover, the expense of evaluating processes that prove to be of limited value to the industry would be greatly reduced.

Preliminary and detailed decisions have been completed for a coal preparation process development facility. The test facility will include a pilot plant, a supporting bench-scale laboratory section, and a coal analysis laboratory.

An update of progress on the Coal Preparation Process Development Facility (CPPDF) shows two major steps:

1. The conceptual and engineering designs have been completed by Birtley Engineering Corporation, Salt Lake City, Utah. The company has submitted the following:
   a. Complete detailed engineering drawings.
   b. Specifications for construction of the coal processing equipment.
   c. An operating manual.
2. The architectural and engineering design has been completed by Williams/Treibilcock/Whitehead, Pittsburgh, Pennsylvania. The following items have been completed:
   a. Master project schedule and definitive cost estimates.
   b. Specifications for site preparation bid package.
   c. Foundation investigation.
   d. Specifications for general, mechanical, electrical work for site development and building construction.

A proposal has been completed for Construction Management Services for the CPPDF and, if approved, should be let by September 1, 1978.

4.1.14 Coal Preparation Plant Computer Model

The University of Pittsburgh has completed the first phase in the development of a computer program that will simulate coal preparation plant operations[20,21]. The program can simulate the following washing devices:

Concentrating table
Dense-medium cyclone
Dense-medium vessel
Hydrocyclone
Baum jig
Froth flotation cell

The program also contains mathematical models for a rotary breaker and for various crushers such as the single-roll crusher, gyratory/jaw crusher, and cage mill crusher. Mathematical models also exist for wet and dry screen performance.

From input in the form of coal analysis by size and specific gravity fractions, the program will predict the output clean coal and output refuse from a given plant configuration.

Work is needed in the following areas:

1. Improvement of the simulation algorithm for froth flotation.
2. Simulation of ash and mineral liberation through crushing.
3. Simulation of thermal dryers.
4. Addition of cost data to allow evaluations of the economic feasibilities of various coal preparation circuits.

### 4.1.15 Engineering/Economic Analysis of Coal Preparation, Operation, and Cost

The Hoffman-Muntner Corporation recently completed a study to identify the costs associated with the various types and levels of physical coal preparation processes currently available. Although data of this type have been generated previously in fragmented form, the objective was to give a comprehensive presentation having a uniform time base. A methodology was developed that permits meaningful comparison of the relative costs of coal cleaning. This technique was applied to current technology and economics and also can be used in the future with appropriate index adjustment.

Eight existing coal preparation plants were selected for analysis. These plants range in complexity from a relatively simple jig plant to a rather sophisticated preparation scheme incorporating dense-medium cyclones, froth flotation, and thermal drying. The report discusses each of these plants separately, with an analysis of the individual process and the level of cleaning achieved, as supported by specific washability data. Additionally, the major cost components, such as capital, labor, and materials are summarized to arrive at the total cost of cleaning for each plant. These analyses are presented from the perspective of the preparation plant operator and do not assess the many user-oriented benefits resulting from coal cleaning. In addition to higher heat content, such benefits include lower costs for emission control, transportation, boiler maintenance, and ash disposal.

Table 12 summarizes the major performance and cost elements from the eight operating preparation plants examined in this study.

### 4.1.16 Chemical Coal Cleaning

A project entitled, "Analysis of Chemical Coal Cleaning Processes", which Bechtel carried out for the Bureau of Mines is presently being updated. The update is to include the Low Temperature Chlorinolysis Process being investigated at JPL. Cost analyses for the initial preparation and final compaction of the coal are being modified to reflect process differences. In addition, the KVB process flow chart will include process information that was unavailable at the time of the initial report.

When these changes are completed, the report will be published.

### 4.1.17 Hydrodesulfurization of Coal

The Institute of Gas Technology (IGT), sponsored by EPA, is developing a chemical coal cleaning process based upon flash hydrodesulfurization of coal[22]. The coal is first pretreated at a temperature of 400°C (and atmospheric pressure) to reduce

TABLE 12. SUMMARY OF PREPARATION PLANT COSTS

| Process | Capacity, Mg/h (ton/h) input | Capacity, Mg/h (ton/h) output | Capital costs, $per Mg/h (ton/h) | Btu recovery | Annualized costs: Dollars per Mg (per ton) of raw coal | Annualized costs: Dollars per Mg (per ton) of clean coal | Annualized costs: Dollars per per GJ (million Btu) |
|---|---|---|---|---|---|---|---|
| Jig-simple | 544 (600) | 321 (351) | 7276 (6600) | 91.6 | 2.17 (1.97) | 3.69 (3.35) | 0.138 (0.146) |
| Jig-intermediate | 907 (1000) | 647 (714) | 15104 (13700) | 96.4 | 2.91 2.62 | 4.04 (3.67) | 0.152 (0.160) |
| Jig-intermediate | 907 (1000) | 513 (566) | 13230 (12000) | 83.0 | 2.45 (2.22) | 4.31 (3.92) | 0.157 (0.165) |
| Jig-complex | 1451 (1600) | 864 (953) | 15766 (14300) | 93.7 | 2.86 (2.60) | 4.81 (4.36) | 0.162 (0.171) |
| Dense medium-simple | 1269 (1400) | 939 (1036) | 15435 (14000) | 94.6 | 3.08 (2.79) | 4.18 (3.76) | 0.185 (0.195) |
| Dense medium-complex | 544 (600) | 396 (440) | 24888 (22400) | 89.2 | 3.93 (3.54) | 5.36 (4.83) | 0.177 (0.187) |
| Dense medium-complex | 544 (600) | 324 (360) | 15555 (14000) | 93.1 | 2.32 (2.09) | 3.86 (3.48) | 0.137 (0.145) |
| Dense medium-complex | 810 (900) | 696 (774) | 25777 (23200) | 94.3 | 3.23 (2.91) | 3.75 (3.38) | 0.135 (0.143) |

caking, and is then processed at 800°C (and atmospheric pressure). The process is dependent upon the proper conditions of temperature, heat-up rate, residence time, coal size, hydrogen partial pressure, and treatment-gas composition. The high temperatures cause considerable loss of heating value due to oxidation, hydrocarbon volatilization, and coal gasification. Average product recovery is about 60 weight percent.

To date, experiments have been carried out only on bench and laboratory scales in order to determine the correct operating conditions. No adequate data exist on the heat and materials balances needed to conceptualize the process design. The laboratory program is currently testing a 10 inch fluidized bed unit which can operate at coal feed rates between 10 and 45 kg/h.

The process can reduce organic sulfur by up to 88 percent and inorganic sulfur by up to 100 percent, depending upon the coal treated. The benefits of the system are that: (a) it produces coal which is burnable in accordance with NSPS without further treatment such as FGD; (b) it reduces the nitrogen content of the coal by 50 percent, thus lowering $NO_x$ emissions; and (c) it could prove to be a major technology for treating coal with a high organic sulfur content. The drawbacks of the process are that: (a) the process has a comparatively low yield; (b) the heating content of the coal is reduced by about 5 percent; (c) the process changes the coal matrix and combustion modifications may be required; (d) $H_2S$ and $SO_x$ are produced as by-products and require further treatment; and (e) the process costs are high.

#### 4.1.18 Environmental Studies on Coal Cleaning Processes

No reports describing the results of this project were available for inclusion in this report.

### 4.2 ENVIRONMENTAL ASSESSMENT

The overall objectives of the environmental assessment activities are to characterize coal contaminants and to identify the fate of these contaminants during coal processing and use.

Initial studies have focused on sulfur and potentially hazardous accessory elements (minor and trace elements) contained in coal. Recent studies have been concerned with a wider range of pollutants - those that may be considered hazardous or toxic under the Water Pollution Control Act (priority pollutants), the Resource Conservation and Recovery Act (hazardous wastes), the 1977 Clean Air Act Amendments (hazardous air pollutants), or the Toxic Substance Control Act. The basic intent of the environmental assessment activities is to identify pollutants that pose health or ecological threats, and to devise cost-effective strategies for dealing with the pollutants.

### 4.2.1 Environmental Assessment Project

A major 3-year project to assess the environmental impacts of coal preparation, coal transportation, and coal storage is being conducted for IERL-RTP by Battelle-Columbus. Some of the major project activities are:

1. Development of a technology overview describing all current coal cleaning processes and the associated pollution control problems.
2. Development and operation of an environmental test program.
3. Development of criteria for assessing the potential health and ecological impacts from coal cleaning processes.
4. Performance of studies to determine the relative environmental impacts of coal cleaning, FGD, and other $SO_2$ emission control methods.

Physical coal cleaning plants have been surveyed, and the data have been analyzed on a geographic basis. The plants have been categorized by state (Table 13). New developments in the fields of physical and chemical coal cleaning have been reviewed and are discussed briefly.

Studies are in progress to develop criteria for assessing the relative environmental hazards associated with pollutants resulting from coal preparation, coal transportation, and coal storage. The set of potential pollutants depends upon the

## TABLE 13. PHYSICAL COAL CLEANING PLANTS CATEGORIZED BY STATES

| State | Estimated total coal production | | Number of coal cleaning plants | Number of plants reporting capacity data | Total daily capacity of reporting plants | | Estimated annual capacity | | Dense medium washers | Number of plants using various cleaning methods | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gg | 1000 tons | | | Mg | tons | Gg | tons[a] | | Jigs | Flotation units | Air tables | Washing tables |
| Alabama | 19432 | 21425 | 22 | 10 | 36824 | 40600 | 9206 | 10150 | 8 | 10 | 6 | 1 | 12 |
| Arkansas | 608 | 670 | 1 | 0 | - | - | - | - | 1 | - | - | - | - |
| Colorado | 7408 | 8168 | 2 | 0 | - | - | - | - | 2 | - | 1 | - | - |
| Illinois | 53741 | 39251 | 33 | 20 | 124055 | 136775 | 31015 | 34195 | 17 | 20 | 4 | 1 | 1 |
| Indiana | 22604 | 24922 | 7 | 6 | 38094 | 42000 | 9524 | 10500 | 2 | 5 | 1 | - | 1 |
| Kansas | 516 | 568 | 2 | 2 | 3447 | 3800 | 862 | 960 | - | - | - | - | - |
| Kentucky | 133238 | 146900 | 70 | 48 | 222850 | 245700 | 55711 | 61425 | 43 | 27 | 16 | 4 | 20 |
| Maryland | 2532 | 2792 | 1 | 0 | - | - | - | - | - | - | 1 | - | - |
| Missouri | 4566 | 5035 | 2 | 1 | 3175 | 3500 | 794 | 875 | - | 2 | - | - | - |
| New Mexico | 8382 | 9242 | 1 | 1 | 5442 | 6000 | 1361 | 1500 | 1 | - | 1 | - | - |
| Ohio | 40436 | 46582 | 18 | 13 | 43194 | 102750 | 23300 | 25690 | 6 | 11 | - | 1 | - |
| Oklahoma | 2512 | 2770 | 2 | 1 | 499 | 550 | 127 | 140 | 1 | 1 | - | - | - |
| Pennsylvania (anthracite) | 4617 | 5090 | 24 | 14 | 11791 | 13000 | 2948 | 3250 | 21 | 4 | 4 | - | 3 |
| Pennsylvania (bituminous) | 74329 | 81950 | 66 | 50 | 258504 | 285010 | 64628 | 71255 | 30 | 19 | 16 | 20 | 15 |
| Tennessee | 8430 | 9295 | 5 | 4 | 7728 | 8520 | 1932 | 2130 | 1 | 1 | 1 | 2 | - |
| Utah | 5986 | 6600 | 6 | 4 | 2095 | 23100 | 5238 | 5775 | 2 | 4 | 2 | 2 | - |
| Virginia | 33106 | 36500 | 42 | 29 | 130200 | 143550 | 32552 | 32552 | 26 | 15 | 9 | 8 | 15 |
| Washington | 3356 | 3700 | 2 | 1 | 18140 | 20000 | 4535 | 5000 | 1 | 1 | - | - | - |
| West Virginia | 99770 | 110000 | 152 | 113 | 523679 | 377375 | 130921 | 144345 | 104 | 55 | 59 | 12 | 55 |
| Wyoming | 21400 | 23595 | 1 | 1 | 544 | 600 | 137 | 150 | - | - | - | 1 | - |
| Total | 546969 | 603055 | 459 | 318 | 1499117 | 1652830 | 374791 | 413210 | 266 | 177 | 121 | 52 | 125 |
| Total (bituminous excluding Pa. anthracite) | 542354 | 597965 | 435 | 304 | 1487326 | 1639830 | 371834 | 409960 | 245 | 173 | 117 | 52 | 122 |

[a] The estimated annual-capacity values for the reporting plants were calculated from the daily-capacity values by assuming an average plant operation of 250 days per year (5 days per week for 50 weeks per year).

boundaries selected. Initially the set was taken to include the combusiton of coal in coal-fired power plants and burning coal refuse piles. Under this interpretation, the myriad of organics formed by the combustion of coal in oxygen deficient regimes (coking-type reactions) was included as representative of gobpile burning. These numbered in the hundreds; over 800 compounds have already been identified from the coking of coal. Many different pollutants have been identified as being associated with raw coal or with some segment of the coal industry.

Reexamination of the problem led to the conclusion that the boundaries of the set should be narrowed to eliminate all pollutants except those directly concerned with coal cleaning. Burning refuse piles at coal cleaning plants are to be considered a mismanagement problem rather than a process problem. Thus, under the redefinititon, the set of pollutants associated with the cleaning of coal includes primarily inorganic compounds associated with the ash fraction. Water would be the principal receptor for these pollutants; operations causing major emissions of air pollutants are infrequent in the cleaning of coal. The largest air emissions would include fugitive dust from coal handling and transfers, and particulates and combustion products from coal dryers.

Within the set of possible pollutants, it was necessary to establish certain criteria for defining actual pollutants; thus, Priority I pollutants were defined as those that have already been identified as pollutants of concern, and whose presence in finite concentrations in coal cleaning processes is known or suspected. These chemical substances were drawn from a number of sources, including EPA criteria pollutants for air; pollutants identified by effluent quidelines for coal mining and preparation; substances included in EPA "Quality Criteria for Water"; and toxic and hazardous pollutants listed by EPA. In addition to these specific pollutants, a number of more general nonchemical pollutants and aggregated pollutant parameters were included. The total list (Table 14) details approximately 80 chemical

TABLE 14. PROPOSED PRIORITY I POLLUTANTS FOR COAL CLEANING PROCESSES

| Pollutant | Pollutant regulations[a] applicable to coal cleaning | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| Aluminum | | | | | | | |
| Antimony | | X | | | | | |
| Arsenic | | X | | | X | | X |
| Barium | | X | | | X | | X |
| Beryllium | | | X | | | | X |
| Boron | | X | | | | | X |
| Bromine | | X | | | | | |
| Cadmium | | | | | X | X | X |
| Calcium | | X | | | | | |
| Carbon | | | | | | | |
| Cerium | | | | | | | |
| Cesium | | | | | | | |
| Chlorine | | X | | | | | X |
| Chromium | | X[b] | | | X | | X |
| Cobalt | | X[b] | | | | | |
| Copper | | X[b] | | | | | X |
| Fluorine | | X | | | | | |
| Gallium | | | | | | | |
| Indium | | | | | | | |
| Iodine | | X | | | | | |
| Iron | | | | | X | | X |

[a]Column headings are defined as follows:

A - National Primary and Secondary Ambient Air Quality Standards

B - OSHA Standards for Workroom Air Contaminants

C - National Emission Standards for Hazardous Air Pollutants

D - New Source Performance Standards (Coal Preparation Plants)

E - Drinking Water Regulations (EPA and PHS)

F - EPA Toxic Pollutant Effluent Standards (Proposed)

G - EPA Water Quality Criteria (Proposed-not regulations)

[b]Metal fume standard.

(continued)

TABLE 14. (continued)

| Pollutant | Pollutant regulations applicable to coal cleaning[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| Lanthanum | | | | | | | |
| Lead | | | | | X | | X |
| Lithium | | | | | | | |
| Magnesium | | | | | | | |
| Manganese | | X | | | X | | X |
| Mercury | | | X | | X | X | X |
| Molybdenum | | X | | | | | |
| Nickel | | X | | | | | X |
| Niobium | | | | | | | |
| Nitrogen | | | | | | | |
| Oxygen | | | | | | | |
| Phosphorus | | | | | | | X |
| Potassium | | | | | | | |
| Rubidium | | | | | | | |
| Selenium | | | | | X | | X |
| Silicon | | | | | | | |
| Sodium | | | | | | | |
| Strontium | | | | | | | |
| Sulfur | | | | | | | |
| Tellurium | | X | | | | | |
| Thorium | | | | | | | |
| Tin | | | | | | | |
| Titanium | | X | | | | | |
| Uranium | | X | | | | | |
| Vanadium | | X | | | | | |
| Zinc | | X | | | X | | X |
| Zirconium | | X | | | | | |
| Groupings | | | | | | | |
| Alkalinity | | | | | | | X |
| Ammonia | | X | | | | | X |
| Cyanide | | X | | | X | X | X |

(continued)

TABLE 14. (continued)

| Pollutant | Pollutant regulations applicable to coal cleaning | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| Chlorides | | | | | X | | |
| Nitrates | | | | | X | | X |
| Sulfides | | | | | | | |
| Sulfates | | | | | X | | |
| $SO_x$ | X | X | | | | | |
| $NO_x$ | X | X | | | | | |
| Total suspended solids (TSS) | | | | | | | |
| Total dissolved solids (TDS) | | | | | X | | |
| Chemical oxygen demand (COD) | | | | | | | |
| Total suspended partic. (TSP) | X | | | X | | | |
| Carbon dioxide | | X | | | | | |
| Carbon monoxide | X | X | | | | | |
| Hydrocarbons | X | | | | | | |
| Photochemical oxidants | X | | | | | | |
| Oil and grease | | | | | | | X |
| Phenols | | X | | | X | | X |
| Organic sulfur compounds | | | | | | | |
| Organic nitrogen compounds | | | | | | | |
| Polycyclic organic materials (POM's) | | | | | | | |
| Carbon chloroform extract (CCE) | | | | X | | | |

substances that have application to coal cleaning processes. From this list a short list has been extracted to be used for preliminary testing of some of the concepts and approaches to the environmental assessment. The short list pollutants are:

| | |
|---|---|
| arsenic | mercury |
| beryllium | nitrates |
| cadmium | nitrogen oxides |
| iron | selenium |
| lead | sulfates |
| manganese | sulfur dioxide |

Pollutants from coal cleaning processes are released as airborne gases and particulates, waterborne ions and compounds, (including dissolved and suspended substances), and elements and compounds associated with solid refuse piles. The ecological impacts of these pollutants can be categorized as effects upon human health, aquatic biota, terrestrial biota, and entire ecosystems.

Many pollutants associated with coal cleaning and burning are toxic to humans. Air pollutants probably pose the greatest health hazard; in addition to their primary direct toxic effects, they cause secondary effects by aggravating existing diseases. The quantity of these emissions can be drastically reduced by prevention of refuse pile fires. Of the water pollutants, heavy metals are of great concern because these toxic trace elements can be leached from coal refuse and storage piles.

Pollutants also have serious effects upon aquatic biota. Heavy metals are often introduced into aquatic ecosystems as by-products of acid mine drainage. Heavy metals are highly toxic to aquatic organisms, especially fish. Some of the heavy metals and related trace elements are also highly bioaccumulative. In addition, they can inhibit photosynthesis, respiration, and growth in various genera of freshwater algae. Freshwater invertebrates are also deleteriously affected. Acidic water emanating from mine drainage of coal piles can seriously alter the pH of

the environment. Suspended solids can also be harmful, reducing light penetration and providing a surface for growth of microorganisms.

These ecological effects can severely affect aquatic biota by endangering the integrity of community structure. For example the integrity of the community structure of algae and protozoa could be seriously damaged by any reduction in the penetration of visible radiation into the ecosystems that would restrict or prohibit the growth of photosynthetic organisms. Predator-prey relationships (e.g., zooplankton grazing on phytoplankton) might change, resulting in abnormal increases or decreases of individuals, thereby causing an upset in the population balance and stability.

Terrestrial biota can also be significantly affected. Table 15 lists some symptoms shown by vegetation from the effects of a variety of air pollutants. The contaminated vegetation may then be ingested by terrestrial animals, who may also be contaminated by (a) inhalation of gases, aerosols, and particulates, (b) ingestion of contaminated water or animals, or (c) absorption of pollutants through the eyes or skin.

The effect upon the ecosystem of a change in the human, aquatic, or terrestrial biota can be serious. A change in vegetation can deprive a particular species of a habitat. The balance of nature is disturbed.

Having defined the pollutants and their effects upon the ecosystem, it is also important to establish permissible media concentrations for each particular pollutant for pollution control development guidance. In view of the state of the art, which is still an emerging technology, the permissible media concentrations are designated as estimated permissible concentrations (EPC's); they are regarded only as estimates, subject to revision as more data become available.

Since a multimedia approach is being taken to the environmental assessment of coal cleaning, EPC's are needed for all three media - air, water, and land; and these will be integral

TABLE 15. POLLUTANT EFFECTS ON VEGATATION

| Pollutant | Symptoms | Maturity of leaf affected | Part of leaf affected | Injury theshold | | |
|---|---|---|---|---|---|---|
| | | | | ppm (vol) | $g/m^3$ | Sustained exposure |
| Sulfur dioxide | Bleached spots, bleached areas between veins, chlorosis, insect injury; winter and drought conditions may cause similar markings | Middle-aged most sensitive; oldest least sensitive | Mesophyll cells | 0.3 | 785 | 5 hours |
| Ozone | Fleck, stipple, bleached spotting, pigmentation; conifer needle tips become brown and necrotic | Oldest most sensitive; youngest least sensitive | Palisade or spongy parenchyma in leaves with no palisade | 0.03 | 59 | 4 hours |
| Peroxyacetyl-nitrate (PAN) | Glazing, silvering, or bronzing on lower surface of leaves | Youngest most sensitive | Spongy cells | 0.01 | 50 | 6 hours |
| Nitrogen | Irregular, white or brown collapsed lesion on intercostal tissue and near leaf margin | Middle-aged most sensitve | Mesophyll cells | 2.5 | 4700 | 4 hours |

(continued)

TABLE 15. (continued)

| Pollutant | Symptoms | Maturity of leaf affected | Part of leaf affected | Injury threshold | | |
|---|---|---|---|---|---|---|
| | | | | ppm (vol) | $g/m^3$ | Sustained exposure |
| Hydrogen fluoride | Tip and margin burn, dwarfing, leaf abscission; narrow brown-red band separates necrotic from green tissue; fungal disease, low and high temperatures, drought, and wind may cause similar markings; suture red spot on peach fruit | Youngest most sensitive | Epidermis and mesophyll cells | 0.1 (ppb) | 0.03 | 5 weeks |
| Ethylene | Sepal withering, leaf abnormalities; flower dropping and failure of leaf to open properly; abscission; water stress may produce similar marking | Young recover; older do not recover fully | All | 0.05 | 58 | 6 hours |
| Chlorine | Bleaching between veins, tip and margin burn, leaf abscission; marking often similar to that of ozone | Mature most sensitive | Epidermis and mesophyll cells | 0.10 | 200 | 6 hours |

(continued)

TABLE 15. (continued)

| Pollutant | Symptoms | Maturity of leaf affected | Part of leaf affected | Injury threshold | | |
|---|---|---|---|---|---|---|
| | | | | ppm | $g/m^3$ | Substained exposure |
| Ammonia | "Cooked" green appearance becoming brown or green on drying; over-all blackening on some species | Mature most sensitive | Complete tissue | ~20 | ~14,000 | 4 hours |
| Hydrogen chloride | Acid-type necrotic lesion; tipburn on fir needles; leaf margin necrosis on broad leaves | Oldest most sensitive | Epidermis and mesophyll cells | ~5-10 | ~11,200 | 2 hours |
| Mercury | Chlorosis and abscission; brown spotting yellowing of veins | Oldest most sensitive | Epidermis and mesophyll cells | < 1 | <8,200 | 1-2 hours |
| Hydrogen sulfide | Basal and marginal scorching | Youngest most affected | | 20 | 28,000 | 5 hours |
| 2,4-Dichlorophenoxyacetic acid (2-4D) | Scalloped margins, swollen stems, yellow-green mottling or stippling, suture red spot (2,4,5-T); epinasty | Youngest most affected | Epidermis | <1 | <9,050 | 2 hours |
| Sulfuric acid | Necrotic spots on upper surface similar to those caused by caustic acidic compounds; high humidity needed | All | All | | | |

parts of multimedia environmental goals (MEG's) that are to be established. EPC's will be germane for air and water media, which man and biota utilize directly. EPC's for soils will be more difficult to establish, due to the fact that there must be a least one transfer before a soil pollutant impacts man.

The establishment of EPC's is recognized as critical to the entire environmental assessment, yet no accepted method has been developed for their determination. Various methods have been attempted, and Battelle has devised a novel series of biological tests. However, there are still tremendous problems in the determination of EPC's, the relevance of animal data to humans being one of the most significant problems.

Concurrent with the development of source assessment criteria, studies are in progress to select coal cleaning sites for environmental testing. The classification of coal sites has been based on four criteria: (a) the acid neutralization potential of the soil surrounding the facility; (b) the pyritic sulfur content of the run-of-mine coal; (c) the average annual precipitation; and (d) the coal cleaning process technology. Based on combinations of the extremes (high and low) for each variable and elimination of combinations that do not occur, ten possible site categories were obtained.

An initial sorting of more than 400 known coal cleaning plants, using information available in the literature, produced lists of facilities corresponding to each of the ten site categories. Where the categories included a large number of cleaning plants, three secondary conditions were imposed to eliminate plants considered undesirable because of field sampling problems. This shortened list includes 46 facilities, to which site visits are planned to obtain unpublished information that will be required before the final selection of the sampling sites.

A master test plan is being developed to ensure a comprehensive test program and to facilitate preparation of site-specific field test plans. The master test plan will identify the potential pollution sources associated with a generalized coal

cleaning plant and will suggest media likely to be impacted by the effluents. Test objectives related to each pollution source will be defined to simplify the process of selecting critical sampling locations and measurements.

Between December 1976 and April 1977 a series of environmental tests were conducted at the Homer City Generating Station in Pennsylvania. The purpose of this monitoring was to evaluate the air, water, and biological quality in the vicinity of the advanced coal cleaning plant then under construction. These studies were conducted prior to the operation of the cleaning plant as a reference point for the future; more comprehensive environmental testing is scheduled during the operation of the plant. Results of the environmental tests are being evaluated.

As in other projects, an extensive review of pollution control technology has been initiated, and is continuing.

### 4.2.2 Coal Contaminants

Three programs are directed to the identification and characterization of contaminants in coal. Specifically, the research attempts to demonstrate the occurrence, association, and distribution of trace elements and mineral phases in the coal seam.

One portion of this research, led by the Illinois State Geological Survey, concentrates on coals of the Illinois Basin. This work has three principal goals: (a) to determine the mode of occurrence and distribution of trace elements and minerals in coal seams; (b) to study the mineralogy and genesis of sulfide minerals in coal; and (c) to evaluate the potential for removal of minerals from coal by various preparation techniques.

The most significant contribution recently was the publication of "Trace Elements in Coal: Occurrence and Distribution"[1], which summarizes results of the past 6 years of EPA-supported activity. The report demonstrates various levels of organic affinities for some of the trace elements in coals. Germanium, beryllium, boron, and antimony all have high affinities for

organic matter, germanium having the highest. Zinc, cadmium, manganese, arsenic, molybdenum, and iron tend to reside with the inorganics, zinc and arsenic being most consistent. A number of elements, including cobalt, nickel, copper, chromium, and selenium, have intermediate organic affinities, suggesting that these metals are present in coals as organometallic compounds, chelated species, or adsorbed cations.

A second area of investigation is being studied by the U. S. Geological Survey in Reston, Virginia. This project has dual objectives. One is to determine the geologic factors which affect or control the physical cleanability of coal and to develop geologic models to help maximize the efficiency and minimize the environmental impact from coal mining, cleaning, and burning. The second objective is to provide chemical, physical, and mineralogical data on the nation's coal resources that will permit evaluation of the environmental impacts resulting from coal preparation and utilization.

The annual report on the first objective of this study is nearing completion; several preliminary conclusions can be drawn on the Upper Freeport coal seam, which the report will address. Despite the complexity of this seam, stratigraphic analysis suggests that facies (geologic zones) in the coal can be mapped throughout the study area. Therefore, those aspects of coal quality that are a function of facies can also be mapped. Mineralogic determinations suggest that quartz, pyrite, kaolinite, illite, and calcite are the most abundant species and that marcasite, siderite, sphalerite, and chalcopyrite occur occasionally. Data on trace elements of environmental concern suggest that arsenic is associated with the iron disulfides, cadmium appears with zinc in sphalerite, and selenium is associated with lead as a lead selenide.

The third study in the area of coal contaminants, being conducted at the Los Alamos Scientific Laboratory (LASL), deals with evaluation of the contaminant potential of coal preparation wastes. The research has three distinct phases:

(a) Characterize the minerals and trace elements, and their association in coal preparation wastes; (b) to study the effects of weathering and leaching on trace elements in coal wastes; and (c) to identify and evaluate techniques for controlling or preventing trace element contamination from coal waste materials. Phases (a) and (b) have been completed, and the results published by EPA[3,23]. Results of the LASL project are discussed in section 4.3 of this report.

### 4.2.3 A Washability and Analytical Evaluation of Potential Pollution from Trace Elements

The DOE has recently completed a study showing the trace element content of various specific-gravity fractions of ten U.S. coals[24]. Most of the trace elements of interest were concentrated in the heavier fractions of the coal, indicating that they are associated with mineral matter. Removal of the high-density fractions of coal should result in trace element reductions, ranging (for some elements) up to 88 percent.

### 4.2.4 Evaluation of the Effects of Coal Cleaning on Fugitive Elements

Bituminous Coal Research, Inc., is evaluating the fate of coal trace elements during mining, transportation, and preparation. It is proposed that 20 run-of-mine samples, representative of U.S. coals, be collected and analyzed. To date, only two samples have been collected. The first was a blend of Upper and Lower Freeport bed coals from the Rochester and Pittsburgh Coal Company in Indiana, Pennsylvania. The second was Illinois No. 6 bed coal from the Old Ben Coal Company in Benton, Illinois. Each sample was crushed and sized, and each size fraction was subdivided into three specific-gravity fractions. Each specific-gravity fraction has been analyzed for arsenic, beryllium, cadmium, chromium, copper, fluorine, lead, manganese, mercury, nickel, selenium, vanadium, and zinc. Analyses are now being performed to determine the relative organic and inorganic affinities of each element.

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## 4.3 DEVELOPMENT OF POLLUTION CONTROL TECHNOLOGY

The subprogram to develop coal cleaning pollution control technology is in a formative phase. A wide variety of techniques is available for controlling conventional pollution problems (total suspended solids, total particulate emissions, pH, etc.), but as coal cleaning processes evolve and as pollution control regulations become more specific and stringent, these techniques must be modified and improved. The subprogram for development of pollution control technology addresses current and projected pollution control needs.

### 4.3.1 Control of Trace Element Leaching from Coal Preparation Plant Wastes

LASL is conducting studies to assess the potential for environmental pollution from trace or minor elements that are discharged or emitted from coal preparation wastes and stored coals, and to identify suitable environmental control measures.

Initial studies were concerned with the assessment of the identities, structure, and chemistry of the trace elements and minerals in samples of high sulfur coal preparation wastes[3]. Extensive quantitative analyses were made of the elemental and mineral compositions of more than 60 refuse samples collected from three coal cleaning plants in the Illinois Basin[24]. Analysis showed these waste materials to be composed mainly of clay minerals (illite, kaolinite, and mixed-layer varieties), pyrite, marcasite, and quartz. Smaller amounts of calcite and gypsum were also identified in some of the refuse samples. The elements present in greatest abundance (silicon, aluminum, iron, sodium, potassium, calcium, and magnesium) are components of the major mineral species. Potentially toxic trace elements found in environmentally significant quantities included manganese, cobalt, nickel, copper, zinc, arsenic, selenium, cadmium, and lead.

The structural relationships and associations among the trace elements and major minerals in the refuse samples were investigated by statistical correlation of chemical and physical data and by direct observation of refuse structure with electron and ion microprobes. It was found that the mineral associations of many of the trace elements that have been identified as being highly leachable from the refuse samples, and therefore, of environmental concern, were with the refuse clay fractions rather than the major pyritic fractions.

In studies completed this year, static and dynamic tests were conducted to determine the trace element leachabilities of the various waste samples. Generally, the trace elements leached in the highest quantities (iron, aluminum, calcium, magnesium, and sodium) are constituents of the major refuse minerals. Several other elements, although not present in the refuse in large amounts, were nonetheless easily removed by leaching. This group included cobalt, nickel, zinc, cadmium, and manganese.

The highest degree of trace element leachability was exhibited by the waste samples that produced the most acidic leachates. Trace element leaching was also found to be a function of refuse particle size (relative surface area), temperature, and access to air.

On the basis of the mineralogy studies, elemental studies, and laboratory leaching experiments, the elements of most concern in the Illinois Basin preparation plant wastes are considered to be fluorine, alumimum, manganese, iron, cobalt, nickel, copper, zinc, and cadmium. These elements are often toxic in aqueous systems or soils, or are present in the refuse in a highly leachable state.

Following completion of the leaching studies, experiments were started to assess potential technologies for (a) preventing the release (leaching) of trace elements from coal preparation wastes, and (b) removing the dissolved trace elements from acidic leachates.

Tests were conducted to evaluate the degree of trace element control that could be exerted by adding neutralizing agents to high-sulfur refuse materials prior to disposal to reduce leachate acidity and trace element dissolution[24]. Column leaching experiments were conducted with mixtures of crushed limestone and refuse to test the effectiveness of this control method. Limestone was combined with the refuse to simulate three geometric arrangements in refuse dumps: placement of limestone on top of the refuse, beneath the refuse, or intermixed with the refuse.

Adding coarse limestone to the acid refuse material was only partly successful in controlling leachate acidity[24]. The pH values of the leachates from most of the refuse-limestone combinations were higher throughout the leaching tests than were those from the refuse alone; however, even in the best instances, neutralization by the in situ limestone was not sufficient to prevent the dissolution of refuse solids (see Figure 10). As expected from the leaching studies, the release of some trace elements was found to be dependent upon the degree of acidity control. Release of elements, such as aluminum, potassium, vanadium, and chromium (which were sensitive to leachate pH), was less from the refuse-limestone systems than from pure refuse. The limestone additions had little apparent effect on the leachate concentrations of iron, manganese, cobalt, copper, and zinc.

Other studies focused on potential control technologies to reduce the content of undesirable trace elements in the aqueous drainages associated with refuse disposal. Tests were conducted to evaluate the degree to which trace element solubilities are affected by treatment with neutralizing agents such as lime, limestone, and lye (sodium hydroxide). These experiments indicated that alkaline neutralization is an effective means for controlling trace element concentrations in refuse wastewater. The iron content and pH of the treated solutions were within acceptable limits, based on 1977 EPA effluent limitation guidelines. Manganese content, however, was a borderline case that sometimes exceeded acceptable limits in the leachates. Lye was generally

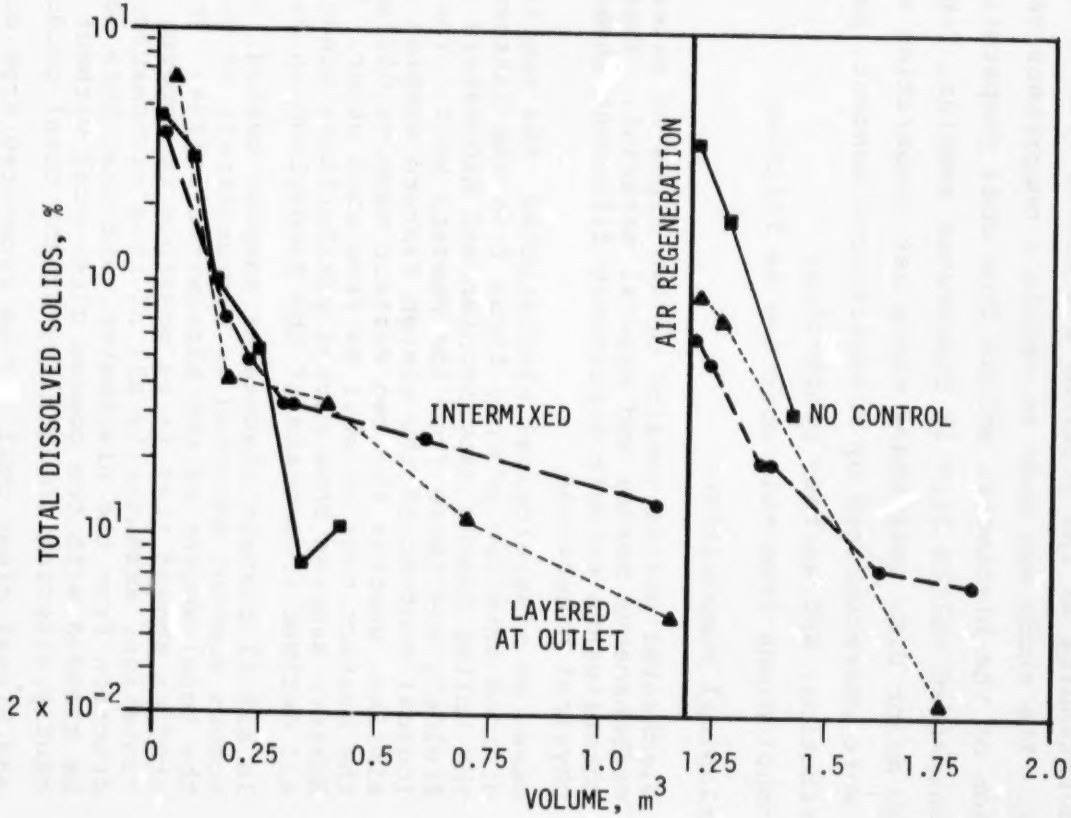


Figure 10. Total dissolved solids vs leachate volume from column leaching study of limestone refuse mixtures.

more effective than limestone or lime in reducing the trace element content of the drainage samples.

### 4.3.2 Control of Blackwater in Coal Preparation Plant Recycle and Discharge

Characterization of the fine solid material in the primary effluent from coal preparation plants provides the basis for a better understanding of the problems associated with treating blackwater. The study was made to obtain a comprehensive characterization of the blackwater solids from coal preparation plants. Suspended solids from 13 blackwater samples, representative of the major U.S. coal seams where wet preparation methods are used, were characterized by mineralogical content, particle size distribution, and surface properties.

The conclusions from this work are as follows:

A. Minerlogical composition

1. Blackwater solids consist of two types of material, carbonaceous matter and mineral material. These constituents exhibit distinctly different chemical and physical properties.
2. Based on mineralogical similarities, the samples were divided into two groups; those from the Eastern half of the United States (Appalachian and Midwestern coal fields), and those from the Western half. The mineralogical content of the eleven Eastern samples was similar, whereas the two Western samples differed from the Eastern ones as well as from each other. The Eastern samples show marked similarities since they are all derived from coals of the Pennsylvanian period.
3. In all 11 Eastern blackwater samples tested, the carbonaceous content amounted to approximately 60 percent of the total weight of the blackwater solids. These studies showed that it is possible to remove, by froth flotation, essentially all of this carbonaceous (coal) fraction from the blackwater, and that this coal could be blended with the coarse clean coal without significantly altering the quality of the total product.
4. Additional clean coal may be recovered from current blackwater discharges from preparation plants by a more extensive use of the flotation process.

5. The average ash content of the carbonaceous fraction removed by froth flotation was 11 percent, as compared to an average of 41 percent ash in the as-received blackwater samples.

6. The mineral fraction of the blackwater solids from Eastern and Midwestern coal fields contains largely illitic clays together with lesser amounts of kaolinite, quartz, calcite, chlorite, and pyrite. Minor amounts of dolomite, feldspar, rutile, or siderite were found in some of the samples.

7. The average mineralogical composition of the mineral fraction from blackwater solids of the eleven samples representative of the "Eastern" coal fields are summarized in Table 16.

8. The high illitic clay content in the Eastern blackwater samples indicates that a large amount of the mineral material in the blackwater is of shale origin. Since shale-derived material is usually soft, it tends to decompose easily during processing. Its presence in the blackwater effluent from a coal preparation plant is therefore virtually assured.

9. Samples from West Virginia, Kentucky, and Alabama contained an illitic material of relatively good crystallinity with very little or no interstratification of montmorillonite with the illite, whereas samples from Pennsylvania, Ohio, Indiana, and Illinois contained an illitic material of varying crystallinity and interstratification.

10. Mineralogy of the two Western samples is different from that of the Eastern samples. Both Western samples contain a large amount of montmorillonite clay. The unique mineral contents of these two samples may be attributed to the fact that these coal seams belong to two different geological periods - the Washington sample from the Tertiary and the Colorado/Utah sample from the Cretaceous.

11. Montmorillonite clay, such as that found in the Western samples, is often more difficult to flocculate efficiently than are illitic and kaolin clays; therefore higher turbidity may be expected in the recycled water from plants treating these Western coals.

12. The primary control of the composition of the mineral matter contained in blackwater is the composition of the adjacent strata, which becomes incorporated into run-of-mine coal during mining.

TABLE 16. PRINCIPAL MINERALS FROM BLACKWATER SOLIDS, EASTERN COAL FIELDS[a]

| | Illite, % | Kaolinite, % | Chlorite, % | Calcite, % | Quartz, % | Pyrite, % |
|---|---|---|---|---|---|---|
| Average | 55 | 11 | 4 | 12 | 15 | 4 |
| Range of average | 47-65 | 6-22 | 0-7 | 0-22 | 8-22 | 1-10 |

[a]Mineral composition of blackwater from plants treating coals dating from the Pennsylvanian period may be expected to be similar to this.

13. The differences in the carbonaceous contents of the 13 blackwater samples are more than likely due to differences in the mining and preparation methods used at the different mines rather than to a difference in the type of coal being mined.

14. The average ash content of pure mineral matter of a typical Eastern sample is about 87 percent. The remaining 13 percent loss is due to the formation of $H_2O$, $CO_2$, $SO_2$, etc., upon heating.

B. Particle Size Analysis

1. Carbonaceous (coal) and mineral fractions from the different blackwater samples produce two distinct size distributions. The carbonaceous fraction is consistently coarser than the mineral matter fraction. On the average, 41 percent of the carbonaceous particles are less than 44 μm, whereas 83 percent of the mineral matter particles are less than 44 μm.

2. Considerable similarity in particle size distribution was found among the 11 Eastern samples. Size distributions in the two Western samples, however, were quite different, probably because of differences in the mineralogy and in the sampling procedures.

3. Typically, the size distributions in the mineral matter tend to be bimodal, probably because of mixtures of "coarse" minerals (quartz, calcite, pyrite, etc.), and "fine" minerals (clays).

4. The size distributions of the mineral matter in the Eastern samples were remarkably similar, presumably because of the similarity of their mineral content. Plots of the particle size distributions of the mineral matter from all 11 Eastern samples yielded a narrow band, with standard deviations ranging from ± 2.2 to ± 9.7 percent, depending on size. A composite size distribution shows that, on the average, 70 ± 9.7 percent of the mineral matter is finer than 10 μm. The fineness of these materials is no doubt due to a high clay content.

5. Similar composite size distributions of the carbonaceous fractions produced standard deviations ranging from ± 0.8 to ± 15.9 percent. The average size distribution of the carbonaceous fraction indicates that this material is much coarser than the mineral matter fraction. The carbonaceous material averages only 21.2 ± 7.3 percent finer than 10 μm.

6. In most of the samples, the high clay content completely dominated the size characteristics of the mineral matter fraction and strongly influenced the overall size characteristics of the blackwater solids.

C. Surface Properties

In the investigation of the surface properties of the principal mineral and carbonaceous constituents, the Zeta potential was measured to determine the electrophoretic mobility of these constituents as a function of pH.

1. Hydronium and hydroxyl ions are potential determining ions for coal and silicate constituents of blackwater. These two mineral categories (coal and silicates) typically account for about 90 percent of the particulate matter in blackwater.

2. Pyrite and the carbonate minerals, mostly calcite, are the only important constituents found in blackwater for which hydronium and hydroxyl ions are not directly the potential determining ions. These minerals are indirectly affected by the concentration of these ions, however, because of the effect of pH on their potential determining ions through the $CO_2/HCO_3^-/CO_3^{2-}$ and $H_2S/HS^-/S^{2-}$ equilibria and through precipitation of metal ions by hydroxyl ions.

3. The point of zero charge (PZC) for the silicate minerals is usually below a pH of 4.

4. The surface properties of the illitic group of clay minerals were highly variable, a reflection of the high degree of structural and compositional variation in this class of clay minerals. For some illites the PZC occurred at pH 2-3, and for others no PZC was found and the particles maintained a negative potential over the entire range studied, pH 2-10.

5. Manipulation of the pH of blackwater suspensions will strongly influence the Zeta potential of the contained mineral matter, and offers a means of controlling the agglomeration of most of the mineral matter. Agglomeration of the silicates, which constitute most of the mineral matter in blackwater, should be favored as the pH of the suspension is lowered. It is not to be inferred that pH control would be the only means, or even the preferred means, of achieving flocculation of the particulate matter in blackwater. In practice, the use of inorganic and organic flocculating agents, such as lime, alum, starch, and polyacrylamides, would usually be the preferred method of flocculation.

6. Since most of the mineral matter in blackwater is clays, the surface properties of these clay minerals will exert a major influence on the surface properties of the suspension as a whole. This effect is magnified because of the small particle size and great surface area of the clays.

7. The large carbonaceous (coal) content in most of the blackwater samples suggests that the surface properties of the coal will also be an important factor in determining the bulk properties of the suspension and the blackwater treatment process.

8. The PZC of the fresh coal samples tested was between pH 3 and 7, decreasing to pH 2 or below as the surface of the coal becomes oxidized. The Zeta potential of most coals is negative for alkaline solutions and decreases in magnitude as the pH is lowered. The surface properties of the carbonaceous constituents of blackwater will depend on a number of factors such as rank, lithotype, degree of oxidation, and chemistry of the blackwater solution.

9. In actual practice one would expect surface properties of the carbonaceous particles in blackwater to be much closer to those of oxidized coal than to those of the fresh coal.

D. Characterization of a Typical Eastern Blackwater Sample

The characteristics of an average Eastern blackwater sample are shown in Table 17.

### 4.3.3 Stabilization of Coal Preparation Waste Slurries

Reject ponds are becoming increasingly impractical because of safety, environmental, and land-use considerations. An alternative approach to the disposal of the fine slurry wastes is the treatment of these wastes to create stable solids, a process termed "stabilization."

Under contract to DOE, Dravo Lime Co. is conducting a study to characterize the engineering, physical, and chemical properties that affect stabilization of fine wastes from coal preparation plants. The requirements and conditions for stabilizing these wastes with and without chemical agents are being determined.

Nine samples were collected from preparation plants in Pennsylvania, West Virginia, Virginia, Illinois, and Indiana.

TABLE 17. CHARACTERISTICS OF A TYPICAL EASTERN BLACKWATER SAMPLE

Solid material

| | Mineral | Carbonaceous | Total |
|---|---|---|---|
| Weight, percent | 40.6 | 59.4 | 100.0 |
| Ash, percent | 84.3 | 10.9 | 41.0 |
| Sulfur, percent | 1.97 | 1.51 | 1.68 |

Mineral composition, weight percent

| Illitic | Kaolinite | Quartz | Calcite | Chlorite | Pyrite |
|---|---|---|---|---|---|
| 55 | 11 | 15 | 12 | 4 | 4 |

Particle size analysis, weight percent-less than

| Size (μm) | Mineral | Carbonaceous | Total |
|---|---|---|---|
| 44 | 86 | 44 | 59 |
| 1 | 22 | 3 | 11 |

Surface properties of principal constituents (coal and silicates)

| | |
|---|---|
| Potential Determining Ions | $H^+$ $OH^-$ |
| Point of Zero Charge | Less than pH 5 |

All samples were subjected to laboratory analyses for index properties, which are permeability, consolidation, penetration, and direct shear, and for stabilization characteristics as a function of variations of additive type (Calcilox, lime, portland cement), dosage, waste solids level, temperature, and time.

The data are being analyzed, and a final report is to be issued in several months. If additional research is warranted, a second phase involving on-site testing with a mobile laboratory will be carried out.

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